UNIVERSITAT DE BARCELONA

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Comparación de un entrenamiento clásico (aeróbico y extensivo) con un entrenamiento mixto (interválico y de fuerza)

Jèssica Bonet Bonet

TESIS DOCTORAL

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Memoria presentada por **Jèssica Bonet Bonet**, para optar al grado de Doctor por la Universidad de Barcelona.

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Dedicat a la meva iaia

Como todos los corredores saben, correr es más que simplemente poner un pie delante del otro; se trata de nuestro estilo de vida y de quiénes somos.

JOAN BENOIT SAMUELSON

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Resumen

Objetivo: Probar la efectividad en corredoras *amateurs* de mediana edad de un programa de entrenamiento de intervalos de alta intensidad (HIIT) para una carrera de media maratón en contraste con un entrenamiento continuo de intensidad moderada convencional (MICT).

Métodos: Veinte corredoras *amateurs* (40 ± 7 años) después de realizar test de campo y de laboratorio, cumplieron con los entrenamientos del programa MICT o HIIT para acabar compitiendo en un medio maratón.
El grupo MICT entrenó una media de 32 km semanales a intensidades por debajo del 80% del VO_2max, mientras que el grupo HIIT corrió 25 km semanales a intensidades entre 80 y 100% VO_2max, combinando rodajes, series, cuestas y trabajo muscular con el propio peso corporal.
Las mujeres que siguieron el HIIT corrieron un 21% menos de distancia e invirtieron un 17% menos de tiempo total de entrenamiento que las del grupo MICT. Todas las mujeres fueron evaluadas al inicio y final del entrenamiento y participaron en el mismo medio maratón. Se obtuvieron muestras de sangre al inicio (S1) y al final de los protocolos de entrenamiento (S2) y 24 horas después de la finalización del medio maratón (S3). Se midieron diferentes parámetros hematológicos, la osmolalidad del plasma y diversos marcadores bioquímicos plasmáticos de estado metabólico general, daño muscular, inflamación y estrés oxidativo.

Resultados: El grupo redujo el tiempo de finalización del medio maratón, comparado con sus logros anteriores, en un 2%-3%, sin llegar a ser significativo. Las series de alta intensidad (200 m y 400 m) y sesiones de resistencia en el programa HIIT promovieron cambios que permitieron modificar la eficiencia en cargas de trabajo elevadas. Al mismo tiempo, el programa de entrenamiento HIIT provocó cambios en el consumo de oxígeno según indicaron los parámetros cardiorrespiratorios obtenidos durante la recuperación en las pruebas de laboratorio. Además, el grupo HIIT registró una disminución

inicial del 14% en la frecuencia cardíaca (HR) que contrasta con la disminución no significativa del 6% en la MICT. Se observaron diferencias interindividuales en la respuesta al entrenamiento presentándose individuos respondedores y no-respondedores, lo que supuso que en algunos parámetros apareciese una elevada dispersión en los resultados. En general, ambos protocolos de entrenamiento indujeron efectos similares moderados en S1 y S2 sobre los parámetros hematológicos y los marcadores bioquímicos plasmáticos de estado metabólico, daño muscular, inflamación y estrés oxidativo. Sin embargo, la respuesta aguda producida por el ejercicio máximo que supone correr una media maratón (valorada a las 24 h de su finalización, S3) indujo una serie de alteraciones hematológicas y plasmáticas compatibles con un estado temporal de fatiga y estrés. Algunas de las alteraciones observadas a las 24 h de la competición, fueron diferentes en función del protocolo de entrenamiento seguido dependiendo de la intensidad, el volumen de carrera y la duración. La intensidad del entrenamiento determinó la vía metabólica y el substrato utilizado como fuente de energía durante la media maratón afectando el perfil lipídico 24 h después de la carrera. El grupo MICT toleró peor que HIIT el esfuerzo agudo que supone la media maratón presentando valores superiores en los marcadores de daño muscular, procesos inflamatorios agudos y estrés oxidativo.

Conclusiones: Las corredoras que siguieron el entrenamiento HIIT obtuvieron registros similares a los de un programa MICT tradicional, empleando menos tiempo y volumen de quilómetros. En referencia a la variabilidad interindividual, se observaron respuestas en ambos grupos, MICT y HIIT, con algunos participantes mostrando mejoras (respondedores) mientras que otros no (no respondedores) en diferentes parámetros de rendimiento, reforzando la idea de que la prescripción de entrenamiento individualizado es necesario para optimizar el rendimiento. Según el tipo de entrenamiento y el parámetro de rendimiento evaluado se observó variabilidad inter-individual en la respuesta al ejercicio, con mujeres respondedoras y no-respondedoras. Ambos entrenamientos indujeron respuestas hematológicas y plasmáticas similares

pero la respuesta aguda a las 24 horas de la finalización del medio maratón varió según el protocolo seguido.

Palabras clave: Mujeres · Mediana edad · Medio maratón · Entrenamiento por intervalos de alta intensidad · Entrenamiento continuo de intensidad moderada · Aeróbico · Respondedores · No respondedores

Resum

Objectiu: Provar l'efectivitat en corredores *amateurs* de mitjana edat, d'un programa d'entrenament d'intervals d'alta intensitat (HIIT) per a una mitja marató en contrast amb un entrenament continu d'intensitat moderada convencional (MICT).

Mètodes: Vint corredores amateurs (40 ± 7 anys) després de realitzar test de camp i de laboratori, van complir amb els entrenaments del programa MICT o HIIT per acabar competint en una mitja marató.

El grup MICT va entrenar una mitjana de 32 km setmanals a intensitats per sota del 80% del VO_2max, mentre que el grup HIIT va córrer 25 km setmanals a intensitats entre el 80% i el 100% del VO_2max, combinant rodatges, sèries, pujades i treball muscular amb el propi pes corporal.

Les dones que van seguir el HIIT van córrer un 21% menys de distància i van invertir un 17% menys de temps total d'entrenament que les del grup MICT. Totes les dones van ser avaluades a l'inici i final de l'entrenament i van participar en la mateixa mitjà marató. Es van obtenir mostres de sang a l'inici (S1) i a al final dels protocols d'entrenament (S2) i 24 hores després de la finalització de la mitja marató (S3). Es van mesurar diferents paràmetres hematològics, l'osmolalitat del plasma i diversos marcadors bioquímics plasmàtics d'estat metabòlic general, dany muscular, inflamació i estrès oxidatiu.

Resultats: El grup va reduir el temps de finalització de la mitja marató, comparat amb les seves marques anteriors, en un 2%-3%, sense arribar a ser significatiu. Les sèries d'alta intensitat (200 m i 400 m) i sessions de resistència, al programa HIIT, van promoure canvis que van permetre modificar l'eficiència en càrregues de treball elevades. Al mateix temps, el programa d'entrenament HIIT va provocar canvis en el consum d'O_2 segons van indicar els paràmetres

cardiorespiratoris obtinguts durant la recuperació en les proves de laboratori. A més, el grup HIIT va registrar una disminució inicial del 14% en la freqüència cardíaca (HR) que contrasta amb la disminució no significativa del 6% en el MICT. Es van observar diferències interindividuals en la resposta a l'entrenament presentant individus responedores i no-responedores, el que va suposar que en alguns paràmetres aparegués una elevada dispersió en els resultats. En general, tots dos protocols d'entrenament van induir efectes similars moderats a S1 i S2 sobre els paràmetres hematològics i els marcadors bioquímics plasmàtics d'estat metabòlic, dany muscular, inflamació i estrès oxidatiu. No obstant això, la resposta aguda produïda per l'exercici màxim que suposa córrer una mitja marató (valorada a les 24 h de la seva finalització, S3) va induir una sèrie d'alteracions hematològiques i plasmàtiques compatibles amb un estat temporal de fatiga i estrès. Algunes de les alteracions observades a les 24 h de la competició, van ser diferents en funció del protocol d'entrenament seguit depenent de la intensitat, el volum de carrera i la durada. La intensitat de l'entrenament va determinar la via metabòlica i el substrat utilitzat com a font d'energia durant la mitja marató afectant el perfil lipídic 24 h després de la cursa. El grup MICT va tolerar pitjor que el grup HIIT l'esforç agut que suposa la mitja marató, presentant valors superiors en els marcadors de dany muscular, processos inflamatoris aguts i estrès oxidatiu.

Conclusions: Les corredores que van seguir l'entrenament HIIT van obtenir registres similars als d'un programa MICT tradicional, emprant menys temps i volum quilomètric. Pel que fa a la variabilitat interindividual, es van observar respostes en ambdós grups, MICT i HIIT, amb algunes participants mostrant millores (responedores) mentre que altres no (no responedores) en diferents paràmetres de rendiment, reforçant la idea que la prescripció d'entrenament individualitzat és necessària per optimitzar el rendiment. Segons el tipus d'entrenament i el paràmetre de rendiment avaluat es va observar variabilitat inter-individual en la resposta a l'exercici, amb dones respondedores i no-respondedores. Tots dos entrenaments van induir respostes hematològiques i

plasmàtiques similars però la resposta aguda a les 24 h de la finalització de la mitja marató, va variar segons el protocol seguit.

Paraules clau: Dones · Mitjana edat · Mitja marató · Entrenament per intervals d'alta intensitat · Entrenament continu d'intensitat moderada · Aeròbic · Responedores · No responedores

Abstract

Objective: To test the effectiveness in middle-aged amateur runners of a high-intensity interval training (HIIT) program for a half-marathon run in contrast to conventional moderate-intensity continuous training (MICT).

Methods: Twenty amateur runners (40 ± 7 years), after performing field and laboratory tests, completed the MICT or HIIT training program and run a half marathon.
The MICT group trained an average of 32 km per week at intensities below 80% of VO_2max, while the HIIT group ran 25 km per week at intensities between 80 % and 100% VO_2max, combining runs, series, up hill running and muscular work with their own body weight. Women who followed HIIT ran 21% less distance and spent 17% less total training time than those in the MICT group. All women were evaluated at the beginning and end of training and participated in the same half marathon. Blood samples were obtained at the beginning (S1) and at the end of the training protocols (S2) and 24 hours after the completion of the half marathon (S3). Different haematological parameters, plasma osmolality and plasma biochemical markers of muscle damage, inflammation and oxidative stress were measured.

Results: The group reduced the half marathon marks, compared to their previous achievements, by 2%-3%, without being significant. The high intensity series (200 m and 400 m) and endurance sessions in the HIIT program promoted changes that allowed modifying the efficiency in high workloads. At the same time, the HIIT training program caused changes in O_2 consumption as indicated by the cardiorespiratory parameters obtained during recovery in laboratory tests. Additionally, the HIIT group recorded an initial 14% decrease in heart rate (HR) that contrasts with the non-significant 6% decrease in MICT. Inter-individual differences were observed in the response to training, presenting responders and non-responders, which meant that in some parameters there was a high dispersion in the results. Overall, both training protocols induced similar moderate effects on S1 and S2 on haematological parameters and plasma biochemical markers of metabolic status, muscle damage, inflammation, and oxidative stress. However, the acute response produced by the maximum exercise involved in running a half marathon (assessed 24 h after its completion, S3) induced haematological and plasma alterations compatible with a temporary state of fatigue and stress, which were different depending on the training protocol. The intensity of the training determined the metabolic pathway and the substrate used as an energy source during the half marathon, affecting the lipid profile 24 h after the race. The MICT group tolerated the acute effort of the half marathon worse than HIIT, presenting higher values in the markers of muscle damage, acute inflammatory processes and oxidative stress.

Conclusions: The runners who followed the HIIT training obtained similar marks to those of a MICT program, using less time and volume of kilometres. Regarding inter-individual variability, responses were observed in both groups, MICT and HIIT, with some participants showing improvements (responders) while others not (non-responders) in different performance parameters, reinforcing the idea that the prescription of individualized training it is necessary to optimize performance. According to the type of training and the performance parameter evaluated, inter-individual variability was observed in the response to exercise, with responding and non-responding women. Both training programmes induced similar haematological and plasma responses but the acute response 24 hours after the end of the half marathon varied depending on the protocol followed.

Keywords: Women · Middle aged · Half marathon · High intensity interval training · Moderate intensity continuous training · Aerobic · Responders · Non-responders

Índice

Lista de tablas y figuras

Abreviaturas

a. C.	Antes de Cristo
ALT	Alanina aminotransferasa *(Alanine aminotransferase)*
AST	Aspartato aminotransferasa *(Aspartate aminotransferase)*
CK	Creatina quinasa *(Creatine Kinase)*
CRP	Proteína C Reactiva *(C-reactive protein)*
CV	Coeficiente de variación
DOMS	Dolor muscular de aparición tardía *(Delayed Onset Muscle Soreness)*
ECG	Electrocardiograma
EDTA	Ácido etilendiaminotetraacético *(Ethylenediaminetetraacetic acid)*
f	Campo (*Field*)
F-UMTT	Test Universidad de Montreal en el campo *(Field UMTT)*
FR	Carrera rápida *(Fast run)*
fTTE	Tiempo hasta el agotamiento en el campo *(field TTE)*
fVO_2max	VO_2max en el campo *(Field VO_2max)*
GGT	Gamma-glutamil transferasa *(gamma-glutamyl transferase)*
GPx	Glutatión peroxidasa *(Glutathione peroxidase)*
GR	Glutatión reductasa *(Glutathione reductase)*
GSH	Glutatión reducido *(Reduced glutathione)*
GSSG	Glutatión oxidado *(Oxidized glutathione)*
HDL	lipoproteínas de alta densidad *(High density lipoprotein)*
HIIT	Entrenamiento interválico de alta intensidad *(High-intensity interval training)*
HR	Frecuencia cardíaca *(Heart rate)*
IAAF	Federación Internacional de Atletismo Amateur *(International Association of Athletics Federations)*
IR	Carrera intervàlica *(Interval running)*
L-TTE	Tiempo hasta el agotamiento en el laboratorio *(Laboratory time to exhaustion)*
L-UMTT	Test Universidad de Montreal en el laboratorio *(Laboratory UMTT)*

LDH	Lactato deshidrogenasa
LDL	Lipoproteínas de baja densidad *(Low density lipoprotein)*
LR	Tirada larga *(Long distance running)*
MAD	Media de las diferencias absolutas *(Mean of the absolute differences)*
MAS	Velocidad máxima aeróbica *(Maximal aerobic speed)*
MCH	Hemoglobina corpuscular media *(mean corpuscular haemoglobin)*
MCHC	Concentración hemoglobina corpuscular media *(mean corpuscular haemoglobin concentration)*
MCV	Volumen corpuscular medio *(mean corpuscular volume)*
MICT	Entrenamiento continuo de intensidad moderada *(Moderate-intensity continuous training)*
MM	Test de la milla *(Magic mile test)*
NADPH	Nicotinamida adenina dinucleótido fosfato en forma reducida *(Nicotinamide adenine dinucleotide reduced)*
O_2Pulse	Pulso de oxígeno *(Oxygen pulse)*
PLT	Plaquetas *(Platelets)*
RBC	Glóbulos rojos *(red blood cells)*
RE	Economía de Carrera *(Running economy)*
ROS	Especies reactivas de oxígeno *(Reactive oxygen species)*
RPE	Percepción del esfuerzo *(Rating of perceived exertion)*
RR	Frecuencia respiratoria *(Respiration Rate)*
S	Muestras de sangre *(Blood samples)*
S1	Punto temporal 1, la semana antes de empezar los programas de entrenamientos *(week before the training programmes began)*
S2	Punto temporal 2, 48 h antes del medio maratón
S3	Punto temporal 3, 24 h después de finalizar el medio maratón
SD	Desviación estándar *(Standard deviation)*
SOD	Superóxido dismutasa *(Superoxide dismutase)*
t	Cinta de correr *(Treadmill)*
TAG	Triacilglicéridos
TAS	Antioxidante total *(Total antioxidant status)*
TGSH	Glutatión total plasmático *(Plasma total glutathione)*

TTE	Tiempo hasta el agotamiento *(Time to exhaustion)*
tTTE	Tiempo de agotamiento en la cinta de correr *(Treadmill TTE)*
tVO_2max	VO_2max en la cinta de correr *(Treadmill VO_2max)*
UH	Cuestas *(Uphill run)*
UMTT	Test de la Universidad de Montreal *(Université de Montréal Track Test)*
VCO_2	Producción de CO_2
V_E	Volumen minuto *(Respiratory minute volumen)*
$\dot{V}O_2$	Consumo de oxígeno *(Oxygen uptake)*
$\dot{V}O_2max$	Consumo máximo de oxígeno *(Maximal oxygen uptake)*
$\dot{V}O_2max$ (%)	Porcentaje del consumo máximo de oxígeno (Uso fraccional)
WBC	Glóbulos blancos *(white blood cells)*
WE	Ejercicios de fuerza con el propio peso corporal *(Own body weight resistance exercises)*

1

Introducción general

1.1 Presentación de las publicaciones

La presente tesis se construye a partir de una serie de artículos científicos producto del trabajo realizado entre los años 2015 y 2020 en el Laboratorio de Fisiología del Ejercicio y la Hipóxia (Departament de Biologia Cel·lular, Fisiologia i Immunologia, Facultat de Biologia, Universitat de Barcelona), el Laboratorio de Fisiología del Ejercicio (Departament de Ciències Fisiològiques, Facultat de Ciències de la Salut i Medicina, Campus de Bellvitge, Universitat de Barcelona) y en LaMetEx - Laboratory of Metabolism and Exercise (Centro de Investigação em Atividade Física, Saüde e Lazer (CIAFEL), Faculdade de Desporto, Universidade do Porto).

La investigación llevada a cabo durante estos años se enmarca principalmente en el desarrollo de un método de entrenamiento para preparar un medio maratón en mujeres corredoras *amateurs* premenopáusicas.

Los trabajos que conforman esta tesis aparecen listados a continuación con números romanos (se utilizará esta enumeración para su referencia a lo largo de la tesis):

I. Bonet JB, Magalhães J, Viscor G, Pagès T, Javierre CF, Torrella JR (2020) **A Field Tool for the Aerobic Power Evaluation of Middle-Aged Female Recreational Runners**. *Women & Health* 60(7), 839-848.

II. Bonet JB, Magalhães J, Viscor G, Pagès T, Javierre C, Torrella JR (2020) **High-Intensity Interval versus Moderate-Intensity Continuous Half-Marathon Training Programme for Middle-Aged Women**. *European Journal of Applied Physiology* 120(5), 1083–1096.

III. Bonet JB, Magalhães J, Viscor G, Pagès T, Ventura JL, Torrella JR, Javierre C (2020) **Inter-individual different responses to continuous**

and interval training in recreational middle-aged women runners. *Frontiers in Physiology* 11:579835.

IV. Bonet JB, Javierre C, Rizo-Roca D, Beleza J, Viscor G, Pagès T, Magalhães J, Torrella JR (2020) **Volume *versus* intensity programme training for a half-marathon: haematological and biochemical parameters in middle-aged women.** (En revisión).

El artículo **I** recoge la creación de una herramienta (fórmula matemática) para cuantificar las cargas de entrenamiento en el campo en la población que nos ocupa, mujeres corredoras premenopáusicas. Se trata de un trabajo metodológico que nace de la necesidad de poder cuantificar los valores de consumo máximo de oxígeno (VO_2max) de manera indirecta con el test de campo de la Universidad de Montreal (UMTT), con la finalidad de poder ajustar de manera individual las cargas de entrenamiento sin necesidad de pasar constantemente por el laboratorio. Para obtener la fórmula matemática, hemos tomado como punto de partida el modelo de ecuación que previamente diseñaron Luc Léger y Robert Boucher en el UMTT (Léger and Boucher 1980).

Teniendo en cuenta que una de las principales barreras a la hora de hacer ejercicio sigue siendo la falta de tiempo (Gibala et al. 2012), esta herramienta nos ayuda a optimizarlo, puesto que podemos realizar el test a distintas personas a la vez y no es necesario desplazarse al laboratorio, minimizando a la vez el coste económico, no olvidemos que son atletas *amateurs*.

El artículo **II** constituye el trabajo central de la tesis. En él se analizan dos tipos de entrenamiento con el objetivo de igualar o mejorar las marcas anteriores en medio maratón realizando un volumen menor de entrenamiento y empleado menos tiempo. Así pues, estamos hablando del desarrollo de las 12 semanas de entrenamiento pensadas para realizar esa competición. Se evalúa la evolución de ambos entrenamientos utilizando la herramienta comentada en el artículo I y, además, se agregan pruebas específicas para determinar parámetros como el VO_2max, la HR, la evolución de la potencia desarrollada durante los entrenamientos de intervalos y en las carreras continuas a ritmo elevado, incluyendo la percepción del esfuerzo en los distintos tipos de entrenamientos.

El artículo **III** hace referencia a la importancia que tiene la respuesta individual al entrenamiento. Se analizó la respuesta a los estímulos del entrenamiento, determinando de esta forma qué sujetos habían sido respondedores a la actividad, es decir habían obtenido buenos resultados y cuáles no habían respondido a esos estímulos, quedándose en el mismo resultado o, incluso, empeorando su rendimiento.

Finalmente, el artículo **IV**, resultado de una estancia doctoral en el *Laboratório de Metabolismo e Exercício* de la Facultad de Desporto de la Universidad de Porto. Este artículo está en revisión i en él se analizan diversos parámetros hematológicos y marcadores bioquímicos plasmáticos con la pretensión de determinar los impactos a nivel de estado metabólico global, daño muscular, inflamación y estrés oxidativo con una comparativa pre-, post-período de entrenamiento y post-medio maratón.

El lector encontrará en las próximas páginas una introducción en la que se presenta el contexto de la tesis y los principales conceptos teóricos, seguida de la presentación de los objetivos, los artículos publicados, la discusión general de los resultados obtenidos y, finalmente, las conclusiones.

1.2 Contexto

¿Por qué hacemos ejercicio físico? Es una evidencia científica que realizar ejercicio físico tiene importantes beneficios sobre la salud de los individuos (Joyner and Coyle 2008, Warburton et al. 2006), además de poder poner a prueba nuestro rendimiento (Hughes et al. 2018).

Entrenar para un medio maratón es una de estas formas de realizar ejercicio físico, proporcionando unos efectos ventajosos sobre los factores relacionados con la salud, mejorando la calidad de vida y reduciendo el riesgo de sufrir enfermedades crónicas derivadas del sedentarismo (Pedersen and Saltin 2015).

Correr, caminar, saltar y lanzar forman parte de los movimientos naturales del ser humano desde los tiempos más remotos pues ya se tiene constancia, gracias a pinturas rupestres de la época del paleolítico inferior (barranco de la Valltorta, Castellón), de que correr era una forma de huir, protegerse o una actividad necesaria para poder cazar.

En las épocas griegas y romanas, encontramos a los *hemeródromos,* mensajeros a pie, que corrían distancias de hasta 100 km para entregar cartas a sus destinatarios. Posiblemente uno de los que más ha trascendido fue Filípides, aunque fue Tersipo el mensajero que recorrió 50 km que anunció que los atenienses habían vencido en el campo de batalla de Maratón, falleciendo justo después a causa del gran esfuerzo.

Esta figura del *footmen* o mensajeros a pie también aparece en el Reino Unido, con referencias del 1040 a. C., siendo considerados en época de los Tudor o los Stuart (1485 a 1714) personas con un reconocido estatus social para los nobles ingleses. (Noakes 2001).

En la actualidad, correr forma parte de nuestra vida como una actividad recreativa, una manera de mantenernos en forma y de preservar nuestra salud o, incluso, como un trabajo para los atletas profesionales. Correr está en el pódium de los deportes más practicados en el mundo, posiblemente debido a su fácil acceso y bajo coste económico. En África es el deporte más practicado, incidiendo en un 9.3% de la población; En la zona del Pacífico Oeste (13.3%), en Europa (11.9%) y Sudeste asiático (11.1%) es el segundo deporte más practicado. Finalmente, en el continente Americano y la zona mediterránea, es el tercer deporte más practicado, llegando a un 8.5% y 11.9% de la población de esos territorios respectivamente (Hulteen et al. 2017).

1.2.1 Mundial

Si contextualizamos el atletismo en el s. XXI, podríamos decir que el primer *boom* del *running* se produjo en los años 70, cuando hubo un crecimiento rápido de este deporte a nivel popular en EEUU, gracias a la presencia de grandes atletas como Steve Prefontaine o Joan Benoit. Este fenómeno, unido a la relación que se estableció entre Bill Bowerman, la Universidad de Oregón y la firma comercial Nike, dio el pistoletazo de salida a este fenómeno, capitaneado por el *Nike Oregon Project.*

La práctica deportiva se ha convertido en estas últimas décadas en un aspecto cada vez más cotidiano y habitual en los países desarrollados. En concreto, según el estudio presentado por Jens Jakob Andersen en la *IAAF Global Running Conference*, con un análisis de 107.9 millones de resultados de carreras y más de 70 mil eventos realizados en Europa y Norteamérica, desde 1986 a 2018 (Andersen 2019) la práctica del *running* creció exponencialmente en todo el mundo entre 2006 y 2016, llegando a 9.1 millones de participaciones en carreras populares en el año 2016. Si bien, se indicaba una disminución de un 13% en los últimos 2 años. En cambio, si observamos la participación en los últimos 10 años, hay un aumento del 57.8% (de 5 a 7.9 millones de participantes) (Andersen 2019).

Las carreras de 5 km y los medios maratones son las que han sufrido la mayor disminución de participación en los últimos 2 años, posiblemente porque los corredores populares buscan retos mayores. Los principiantes a veces tienen el concepto que las carreras de 5 km son poca distancia y prefieren las de 10 km, mientras que los experimentados no quieren hacer medios maratones cuando pueden completar la mítica distancia del maratón. Los resultados de participación en las carreras de 10 km y los maratones se han mantenido bastante estables, sólo con fluctuaciones del 2% estos dos últimos años, como podemos apreciar en la Figura 1 (Andersen 2019).

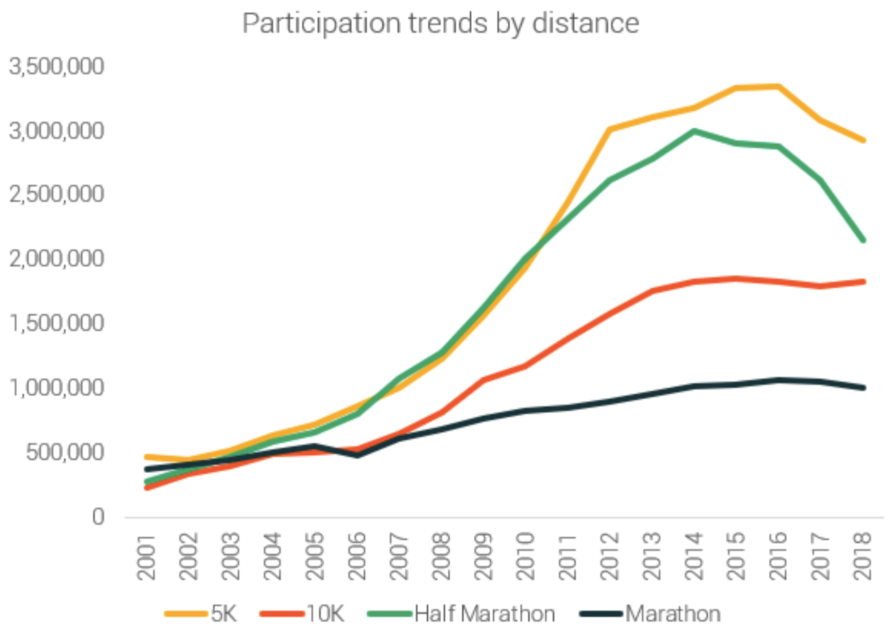

Figura 1. Participación según distancia (Andersen 2019).

Desde 2017 ha disminuido un poco el ritmo de crecimiento de este deporte, tal y como indica el estudio *State of Running* (Andersen 2019) debido, principalmente, a la reducción observada en Europa y los Estados Unidos, sin compensarse por el aumento observado en Asia. En resumen, la práctica del *running* alcanzó su punto máximo en 2016 con un total de 9.1 millones de resultados en distintas carreras y disminuyó a 7.9 millones (una disminución del 13%) en 2018.

La edad promedio de los corredores en 1986 era de 35.2 años, mientras que en 2018 de 39.3 años. Esto podría deberse al hecho de que los corredores están activos durante más años y/o que empiezan a correr a una edad más avanzada. Si nos centramos en la prueba que nos ocupa, el medio maratón, la edad más frecuente es de 37.5 a 39 años (Andersen 2019).

1.2.2 Mujeres

Si hacemos un breve resumen de la participación de la mujer en competiciones de atletismo, nos tenemos que remontar hasta 1928 para ver la primera participación en un campeonato en 800 m, la prueba más larga que se les dejaba realizar hasta el momento, y que después de que algunas de ellas llegaran desfallecidas a la línea de meta, se volvió a prohibir hasta 1960. En 1972 es la primera vez que se correrán los 1500 m en los JJOO y que 8 mujeres correrán, de forma legal, el maratón de Boston; previamente, en 1966 Bobbie Gibb y en 1967 Kathrine Switze, corrieron esta prueba de manera extraoficial. Tuvimos que esperar a los JJOO de los Ángeles 1984 para que Joan Benoit ganara el primer maratón olímpico femenino.

En 1998 participaron 3500 mujeres en el maratón de Boston y 9000 en el de Nueva York. Con el boom del atletismo, y sobretodo en EEUU, ha aumentado mucho la participación femenina en medios maratones y maratones hasta llegar a ser el 43% del total de participantes, mientras que a nivel mundial es de un 31,36% y muy por debajo está esta estadística en España, con sólo un 13% de mujeres participantes en maratón (Andersen 2019). Si analizamos los datos de participación femenina en nuestro país, y concretamente en las 3 pruebas con más participación, encontramos que tenemos un 34% de participación femenina en el medio maratón y un 20% en el maratón de Barcelona; un 20% en el medio maratón y 14% en el maratón EDP Rock´n Roll Madrid; y finalmente un 24% en el medio maratón y 16,6% en el maratón de Valencia.

Si acotamos todavía más a la participación por edad, las corredoras que tienen alrededor de 40 años, en el año 2000 en EEUU, era un grupo minoritario (Brownson et al. 2000), mientras que en la actualidad, por primera vez en la historia, hay más corredoras femeninas que corredores masculinos, concretamente en 2018 el 50.2%, manteniendo la media de edad alrededor de los 36 años (Andersen 2019).

1.2.3 España

En España, la práctica del *running* se ha extendido a gran velocidad y, en parte, gracias a que cada vez se practica más entre la población femenina. En la figura 2 podemos ver la evolución desde el año 1996 al 2019, según los datos publicados por el web *Statista* (AIMC 2020).

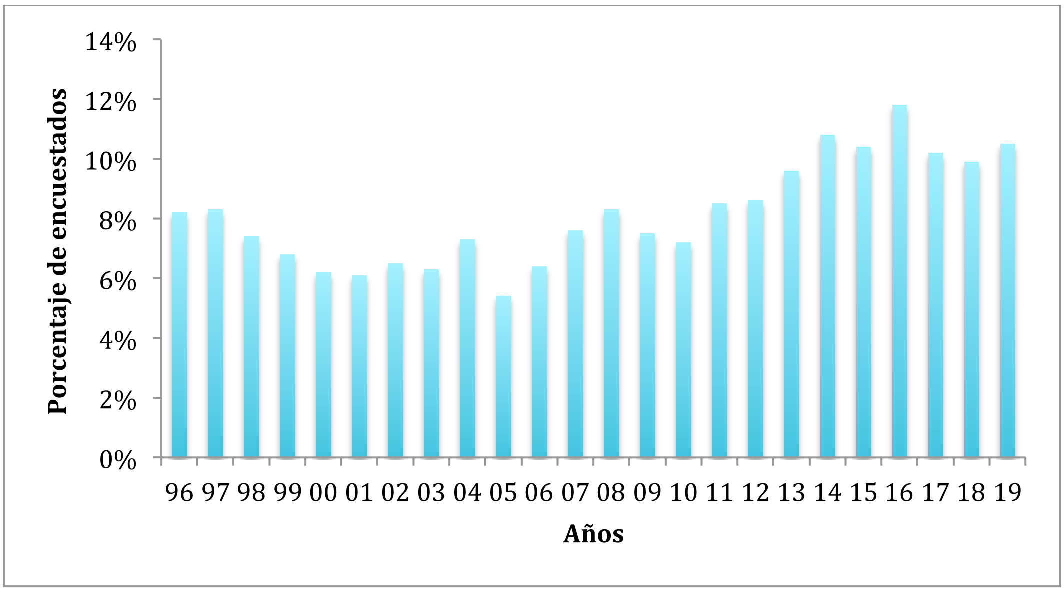

Figura 2. Con un total de 29.097 encuestados mayores de 14 años se indica el % de encuestados que corrían en cada año. Fuente: AIMC 2020 .

Por otro lado, la empresa Nielsen Sports España eleva la cifra de participación en el mundo del *running* hasta el 74% en la población entre 16-29 años; 68% en el grupo de edad que más nos interesa a nosotros, de 30 a 49 años, y finalmente un 40% entre los 50 y 69 años (Nielsen Sports 2017).

El segmento de los corredores que entrenan 3 días o más por semana, comprende al 33% de la población corredora, está en la horquilla de edad de 30 años y 49 años, principalmente (56%), donde un 57% son hombres y un 43% mujeres (figura 3).

Figura 3. Adaptada de la fuente: Nielsen Sports España (2017). Participación masculina y femenina entre los 16 y 69 años de edad.

En cuanto a la participación femenina en las carreras populares, está todavía lejos de equipararse con la participación masculina en pruebas de medio maratón y maratón, pero ya se está empezando a ver en las pruebas populares de 10 km. Recientemente, en los 10 km del EDP maratón de Madrid, las inscripciones de mujeres superaron el 50% y un 32% en el medio maratón, mientras que en los 10 km de Valencia se llegó al 46% de participación femenina y en el medio maratón de Barcelona a un 34%.

Fenómeno a parte es la Carrera de la mujer, en sus orígenes, en 2004, tenía una participación de 3400 corredoras. Ahora, en la última edición de 2019, ha contado con 36.000 participantes tanto en Barcelona como en Madrid, siendo el evento deportivo femenino más grande de Europa.

Un reciente estudio que revisa la participación en las carreras populares, hecho por diversos expertos en *running* del país, explica que entre 2008 y 2013 el número total de participantes que terminaron maratones en España se ha duplicado, pasando de poco más de 28.000 en 2008 a cerca de 57.000 en 2013. Se estima que un 53% de los participantes tienen una edad cercana a los 40 años (Suanzes 2014).

Si hacemos referencia a la participación femenina, es significativa la diferencia en el porcentaje del 43% de mujeres entre los corredores que terminan los maratones en Estados Unidos frente al 10% de España: más de 232.000 en Estados Unidos en comparación con 5.500 en España. En términos comparativos, un peso similar de la participación de mujeres en España supondría la incorporación de cerca de 30.000 corredoras adicionales (González Pacheco 2014).

En el estudio *The state of running* (Andersen 2019) con un análisis exhaustivo de 107.9 millones de resultados de carreras, desde el año 1986 hasta el 2018, indica las siguientes tendencias en el mundo del *running*:

- Las carreras de 5 km y los medios maratones contrariamente a lo que pasa en EEUU, son las carreras con más éxito, probablemente porque unas son para iniciarse y las otras un reto personal cuando ya llevas un tiempo en el mundo del *running*.
- Si analizamos la distancia que corren los corredores en cada sesión de entrenamiento en función de su nivel, se observa que puede ir de 5 km a 20 km por sesión. En nuestra población de estudio, mujeres con un nivel *amateur*, más del 60% suele correr entre 5 km y 10 km por sesión (figura 4).

Y si observamos el volumen de km mensuales, según la agencia EFE (Practico Deporte 2019) un 32% superaría los 50 km, y alrededor del 20% estaría entre los 21 km y 30 km. Aumenta el número de *runners* españoles aficionados a las carreras populares.

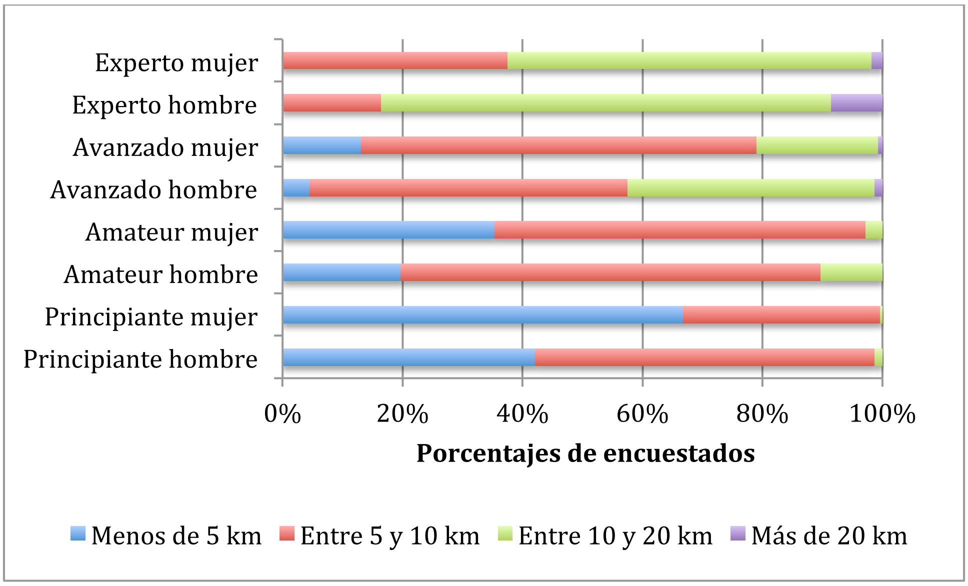

Figura 4. Diferenciación entre corredores según su nivel, otorgando categoría de Principiante: personas que se inician en el mundo del *running* pero sin una asiduidad semanal. Suelen salir a correr de manera esporádica sin tener el hábito adquirido. *Amateur:* personas que salen entre 3 y 5 días por semana con el objetivo de mantenerse en forma o por salud, no para correr carreras. Pueden participar en alguna prueba con amigos y sin objetivos. Avanzado: personas que corren como mínimo un par de veces por semana y participan en más de 3 pruebas al año. Corren para mantenerse en forma y se preparan para alguna prueba en concreto con el objetivo de hacerlo lo mejor posible. Experto: corren más de 3 veces por semana y preparan carreras con el objetivo de superarse y asumir retos. Porcentaje encuestado: 75,9% hombres y 24,1% mujeres.

1.2.4 Motivación

La motivación hacia la práctica de las carreras populares de fondo en el grupo de población aficionada, desde los 10 km al maratón, ha sido analizada por diversos autores (Llopis y Llopis 2006, García Ferrando 2001), llegando a la conclusión que hay distintas motivaciones para que las personas corran recreativamente que podemos ver en las figuras 5 y 6. La población femenina está aumentado significativamente en la participación de pruebas deportivas, pero todavía queda camino hasta llegar al mismo porcentaje de ambos sexos en pruebas como los medio maratones o maratones, sobre todo en nuestro medio.

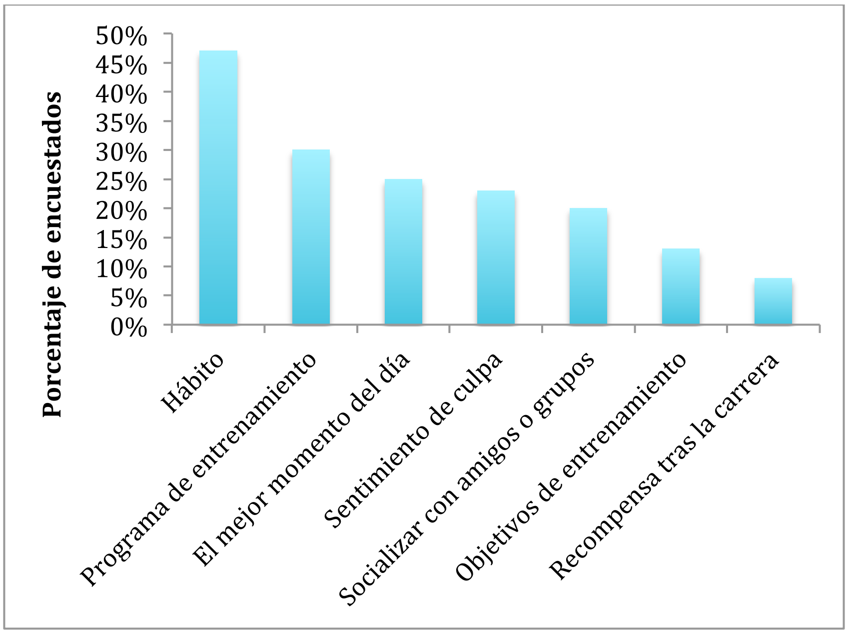

Figura 5. Motivaciones para salir a correr de los *runners* encuestados. Adaptado de Strava (2020).

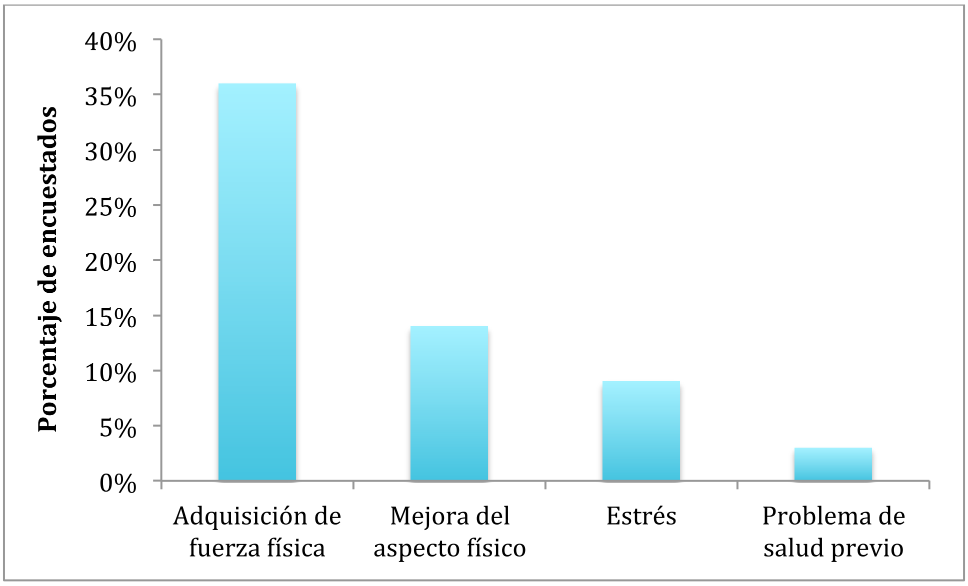

Figura 6. Motivos de salud por los cuales los individuos empiezan a correr. Adaptado de Strava (2020).

1.3 Factores que determinan el entrenamiento de pruebas de larga duración

Tres variables fisiológicas son las principales condicionantes que intervienen en el rendimiento de la resistencia (Coyle 1995): el consumo máximo de oxígeno (VO_2max), el umbral anaeróbico y la economía de carrera.

1.3.1 Consumo máximo de oxígeno (VO_2max)

Desde la década de 1920, los investigadores en la fisiología del ejercicio prestaron considerable atención al VO_2max, siendo uno de los más estudiados en ese campo. Hill y colaboradores (Hill et al. 1924) establecieron el concepto de VO_2max y los criterios para determinar el requerimiento de oxígeno para diferentes actividades de ejercicio a varias velocidades. Esos autores consideraron que el consumo de oxígeno, en litros por minuto, es "una medida de la energía necesaria para llevar a cabo una serie dada de movimientos musculares" y concluyeron que "es un criterio cuantitativo valioso del esfuerzo realizado". También comentaron las limitaciones, debido a la capacidad finita del sistema circulatorio y respiratorio, de aumentar el consumo de oxígeno más allá de un punto máximo. Una buena definición consideraría el VO_2max como la capacidad máxima integrada de los sistemas pulmonar, cardiovascular y muscular para absorber, transportar y consumir oxígeno por unidad de tiempo (Poole et al. 2008). Aunque algunos autores han planteado la hipótesis de que el sistema nervioso central juega un papel en la limitación del intercambio pulmonar en la absorción máxima de oxígeno (Weir et al. 2006), se ha establecido que el VO_2max "está limitado por la capacidad del sistema cardiorrespiratorio para transportar O_2 a los músculos” (Noakes and Marino 2009). Además, se acuerda que un VO_2max alto es un requisito previo para tener éxito en carreras de media y larga distancia (Saltin and Astrand 1967).

Dado que las pruebas para determinar el VO_2max se estandarizaron por Taylor et al. (1955) varios informes han demostrado que, aunque existen diferencias en la superficie de carrera, la corriente de aire y los patrones de movimiento entre correr en una cinta y en una pista (Meyer et al. 2003), no presentan diferencias significativas entre los valores de VO_2max obtenidos en el laboratorio y en una pista (Noakes 1990).

Los entrenadores también usan otras medidas comunes para evaluar el ejercicio de resistencia en la pista y el campo. Una de ellas es la velocidad aeróbica máxima (MAS, maximal aerobic speed), definida como la velocidad de carrera a la que un individuo puede alcanzar el VO_2max (Billat et al. 1996). Para obtener la MAS y el VO_2max al mismo tiempo, es necesario utilizar un analizador de gases portátil, que presenta serios inconvenientes logísticos y aumenta los costes económicos.

Otro parámetro que se usa comúnmente para evaluar el rendimiento y el entrenamiento es el tiempo hasta el agotamiento (TTE) durante una prueba incremental en una cinta ergométrica. TTE se define como el tiempo después del cual el individuo ya no puede mantener el ritmo de la cinta (Kaynak et al. 2017). Los TTE más largos, junto con aumentos en otros parámetros como VO_2max, MAS y economía de carrera (running economy, RE), se han considerado factores importantes que mejoran la resistencia aeróbica (Bangsbo et al. 2009).

1.3.2 Umbral de lactato

El concepto de umbral de lactato apareció por primera vez en 1959, de la mano de los científicos Hollmann and Hettinger, en el *Third Pan-American Congress of Sport Physicians* en Chicago (Hollmann 2001). Fue en 1985, cuando Davis describió el termino umbral anaeróbico como la intensidad de ejercicio o de VO_2max más allá de la cual el ácido láctico comienza a acumularse en la sangre desencadenando una acidosis metabólica (Davis 1985). La concentración de lactato en sangre representa la relación existente entre la producción y la eliminación en un momento determinado. Cuando realizamos ejercicio a una intensidad elevada los músculos no pueden mantener el equilibrio entre la producción y demanda de energía mediante el sistema aeróbico, en este momento la concentración de lactato empieza a aumentar exponencialmente. Se introdujo el concepto del umbral de los 4 mmol·L^{-1} (Mader et al. 1976) y la importancia del umbral de lactato para controlar el entrenamiento aeróbico de los atletas (Heck et al. 1985).

Una de las diferencias entre individuos entrenados y no entrenados es a qué porcentaje de su VO_2max alcanzan este umbral. Los no entrenados cuando el esfuerzo supera el 55-70% del VO_2max y en los entrenados entre el 80-90% del VO_2max (Hoffman 2014).

1.3.3 Economía de carrera

El concepto de economía de carrera se relaciona con la cantidad de oxígeno utilizado por el atleta cuando corre a una velocidad de carrera constante. Algunos autores han demostrado que este factor puede explicar parte de la variabilidad en el rendimiento de carrera en individuos con similares VO_2max (Basset and Howley 1977). Pero hay discrepancias respecto a su definición y relación con otros factores (Barnes and Kilding 2015): VO_2 submáximo para una tarea dada como eficiencia fisiológica; eficiencia muscular; proporción del trabajo realizado a la energía gastada; coste de oxígeno; coste de energía. Incluso como un concepto multifactorial dónde intervienen el entrenamiento de resistencia, fuerza, flexibilidad, factores medioambientales o la nutrición (Barnes and Kilding 2015).

1.4 ¿Cómo han progresado los métodos de entrenamiento?

El atletismo, ya estaba presente como disciplina en los antiguos Juegos Olímpicos o en los Juegos Píticos. Aunque poco sabemos de sus rutinas de entrenamiento, Hegedüs (1984) apunta que se sabe que se sometían a una férrea disciplina de un entrenamiento que ya contemplaba diversos medios de cargas de trabajo, ciclos de programación y ciertos conceptos técnicos.

El hecho de popularizar el atletismo y convertirse en *running* hizo que los entrenadores más prestigiosos adaptaran sus entrenamientos a los atletas más populares. Como ejemplo de este fenómeno tenemos varias propuestas. Higdon (2016) propone 12 semanas de entrenamiento específico para el medio maratón con un rango de entre 28 km - 55 km a la semana, haciendo 5 días de entrenamiento de carrera y 1 día de entrenamiento aeróbico cruzado (bicicleta, natación...). La entrenadora del *Leukemia and Lymphoma Society's Team* y columnista del *Women's Running Magazine*, Christine Luff propone 5 días a la semana de entrenamiento de *running* con un volumen de 24 km a 40 km (Luff 2020). Sin dejar de lado, a uno de los *gurus* del *running* en Norteamérica, Jeff Galloway, se le conoce como "El entrenador de Estados Unidos", que ha entrenado a más de 200.000 personas *amateurs*. Propone 4 días de entrenamiento de carrera a la semana con un mínimo de 32 km a la semana, hasta llegar a 55 km (Galloway and Galloway 2012).

Estamos hablando de programas de entrenamiento con un mismo denominador común: el volumen de la carga de trabajo, con un mínimo de 4 sesiones a la semana. Probablemente, estos volúmenes de entrenamientos podrían ser excesivos para deportistas *amateurs*, dado que la realidad es que no se dispone de mucho tiempo para hacer deporte.

1.4.1 Medio Maratón

El auge del *running* ha puesto de manifiesto los déficits de la preparación específica debido a la falta de tiempo o a la mala información que gestionan los corredores populares (Stutts 2002), produciendo que no vean su progresión o que se lesionen demasiado a menudo (Nielsen et al. 2012).
Este es uno de los principales motivos por los que los corredores *amateurs* deberían seguir un plan de entrenamiento personalizado, adaptando el

programa de entrenamiento y las cargas de trabajo para la preparación de sus carreras.

Si nos focalizamos en un estudio realizado en Suiza, dónde se analizan los datos de todos los medios maratones celebrados en ese país entre 1999 y 2014, observamos el impresionante aumento de participantes, pasando de 7.767 a 454.352 finalistas anuales (Knechtle et al. 2016); siendo los mayores aumentos en las corredoras, que en el año 1999 participaron 1674, mientras que en el 2014 fueron 14.336. En cuanto a la edad, la mayoría de los finalistas se registraron en el grupo de edad de 40 a 44 años. Por lo tanto, extrapolando estos datos podríamos decir que teniendo en cuenta la media de edad de los participantes femeninos, que encaja perfectamente con los sujetos analizados en nuestro estudio, es de gran importancia poder aplicar planes de entrenamiento específicos para mujeres *amateurs* de mediana edad que quieran hacer medio maratón, debido a su alto índice de participación.

1.4.2 Las bases del entrenamiento de resistencia

Se apunta a que las bases del entrenamiento de resistencia las crearon los finlandeses junto a su gran atleta Paavo Nurmi, también conocido como el finlandés volador, en los años 20. Entrenamientos a base de largas caminatas en el período de preparación, pudiendo llegar hasta los 30 km. Sobre esa base se añadían *sprints* de 80-100 m, intervalos de hasta 600 m y “rodajes” (carreras continuas) rápidos de 4 a 7 km (Noakes 2001).

Posteriormente, en los años 50, se pasó al entrenamiento de intervalos atribuido a Stampfl, contribuyendo a la era de oro de la media distancia británica. Se hacían, por ejemplo, 10 series de 400 m con 2 minutos de recuperación a trote. Pero el atleta que revolucionó el entrenamiento a ritmos de carrera fue el checo Emil Zatopek, que utilizó este método repitiendo hasta la saciedad series de 400 m (Noakes 2001).

Newton, en los años 50, introdujo el concepto de volúmenes altos de entrenamiento (mucha distancia y, por lo tanto, tiempo). Peters, también en la misma década, reformuló e introdujo la combinación entre Zatopek y Newton hasta llegar a uno de los grandes entrenadores, Arthur Lydiard. Éste último, en los años 60 consiguió llevar a los neozelandeses a lo más alto de la elite del atletismo en pista, que desarrolló el concepto de *peaking*, es decir, incrementar el volumen de entrenamiento añadiendo sesiones de velocidad en forma de intervalos durante un período de 4 a 6 semanas antes de la competición (Lydiard 1978). Posteriormente, Bowerman ordenó los ritmos para que no siempre fueran todos los entrenamientos interválicos a la misma intensidad (Lydiard 1978).

Sebastian Coe apostó por un entrenamiento de menor volumen y alta intensidad, mientras que algunos de sus competidores optaban por aumentar el volumen en detrimento de la intensidad (Noakes 2001).

Paralelamente, en Kenya, el hermano O'Connell, empezó a introducir el entrenamiento en pista además de realizar 13 sesiones de entrenamiento semanales, entrenamientos de poco volumen por sesión y basados más en entrenamientos de “calidad” (intensidad elevada) con ejercicios de técnica de carrera, *sprints* y cuestas. Consiguió que 25 de sus atletas fueran campeones del mundo.

La aplicación de conceptos científicos también hizo que se cambiaran algunos protocolos, ahora las intensidades pasarían a medirse por las distintas zonas de trabajo respecto al VO_2max o el umbral anaeróbico.

Pero la realidad es que este tipo de entrenamientos no deberían ser la guía para los atletas *amateurs*. Vamos a poner un ejemplo práctico, el tiempo medio empleado en terminar el maratón en EEUU es de 4 h 30 min en hombres y de 4 h 56 min en mujeres; si nos fijamos en los atletas de élite su ventana de tiempos va entre 2 h 2 min y 2 h 10 min los hombres y entre 2 h 15 min y 2 h 25 min las mujeres.

Una corredora de élite va a un ritmo de entre 3 min 11 s a 3 min 26 s el kilómetro; mientras que las corredoras *amateurs* podrían terminar el maratón entre 4 h y 4 h 56 min, por lo tanto, empleando entre 5 min 41 s y 7 min el kilómetro. De estos datos podemos obtener algunas conclusiones prácticas: si las corredoras *amateurs* tuviesen que realizar un rodaje de 25 km deberían emplear entre 2 h 22 min y 2 h 55 min, mientras que las corredoras de élite necesitarían 1 h 25 min. A nivel fisiológico y estructural, correr 1 h más para realizar el mismo entrenamiento supone un impacto mayor, con lo que el cuerpo no va a recuperar de la misma manera. Este es uno de los grandes problemas de los corredores populares, imitar el entrenamiento de los atletas de élite. Por todo ello, es importante considerar que se deben diseñar los entrenamientos respecto a las características de cada individuo, teniendo en cuenta la capacidad y asimilación de carga que posee cada uno de ellos para no provocar lesiones (Noakes 2001).

Según el estudio realizado por Damsted (Meeusen et al. 2013, Soligard et al. 2016), el riesgo de lesión aumenta de manera inversamente proporcional a medida que disminuye la experiencia del corredor, indicando que los corredores que realicen el medio maratón a un ritmo menor también estarán expuestos a un mayor número de lesiones.

1.4.3 High Intensity Interval training (HIIT)

1.4.3.1 Introducción

Se tienen conocimientos que desde 1912 un atleta finlandés, Juho Pietari "Hannes" Kolehmainen, ganador de varias medallas olímpicas en los JJOO de Estocolmo 1912 y Amberes 1920, preparaba los 10 km con entrenamientos interválicos de alta intensidad (HIIT). Su entrenador, Lauri Pihkala, el mismo que tubo Paavo Nurmi, dejó descrito el tipo de entrenamiento que realizaban «a principios del S.XX se basaba en realizar quilómetros a ritmo lento y puntualmente algún entrenamiento a unos ritmos más elevados» (Rius 2020) pero los finlandeses introdujeron el concepto "Tempo", carrera rápida.

Más recientemente, fueron Tabata (Damsted et al. 2017) y Billat (Tabata et al. 1996) quienes hicieron explosionar el entrenamiento interválico de corta duración y alta intensidad. En sus estudios obtuvieron mejoras tanto en la capacidad anaeróbica como en el VO_2máx. Se ha revisado para muchas disciplinas deportivas que el sistema HIIT es un poderoso estímulo para inducir adaptaciones tanto centrales (cardiovasculares) como periféricas (músculo esquelético) que conducen a mejorar la capacidad de ejercicio (Billat et al. 2000). Con respecto a los programas de entrenamiento para correr, se han probado varios HIIT en la última década, lo que resulta en adaptaciones efectivas del estado físico a pesar del menor volumen de ejercicio total realizado (Gibala and McGee 2008).

1.4.3.2 ¿Qué es el Entrenamiento interválico de alta intensidad?

Cuando hablamos de entrenamiento de alta intensidad, nos referimos al término popularmente conocido en inglés como HIIT, *High Intensity Interval Training*. Un entrenamiento con intervalos cortos de actividad a alta intensidad, intercalados por períodos de descanso o ejercicio de baja intensidad (Hazell et al. 2014, McEwan et al. 2018), distinto del entrenamiento continuo descrito como el ejercicio continuo de intensidad media y con una duración entre 30 y 120 minutos (Shepard and Shek 1999)

Pensamos que el entrenamiento HIIT, basándonos en la literatura científica y en la experiencia propia como entrenadora de atletismo, se puede utilizar como una alternativa efectiva al entrenamiento de resistencia tradicional, lo que resulta en cambios similares o, incluso, mejores en una variedad de biomarcadores fisiológicos, de rendimiento y relacionados con la salud, tanto en individuos sanos como en individuos con enfermedades crónicas (Gibala et al. 2012). Distintos investigadores (Gibala et al. 2012, Hwang 2011) observan mejoras similares inducidas por el entrenamiento en varios marcadores de los músculos esqueléticos y en la adaptación cardiovascular, a pesar de las grandes diferencias en el volumen de entrenamiento semanal (aproximadamente un 90% más bajo en el grupo HIIT), mostrando una reducción en el tiempo (aproximadamente un 67% menor en el grupo HIIT) en comparación con el entrenamiento de resistencia tradicional (Burgomaster et al. 2008). Después de realizar varias semanas de HIIT, los autores citados anteriormente avalan el entrenamiento HIIT como una herramienta eficiente que resulta una buena estrategia para inducir adaptaciones rápidas en el músculo esquelético, como lo demuestran los cambios oxidativos contenido/actividad de proteínas enzimáticas, el aumento de contenido mitocondrial en el músculo, el aumento de la eficiencia metabólica, así como una mejoría a la sensibilidad a la insulina. En base a los resultados, se propondría las intervenciones HIIT como alternativa a un entrenamiento continuo más tradicional que requieren de más tiempo de dedicación.

Este tipo de entrenamiento también proporciona una mayor adherencia por ser más divertido (Gibala et al. 2012). En general, muchos sujetos afirman que no realizan las sesiones correspondientes de un entrenamiento clásico por falta de tiempo o por falta de motivación de los entrenamientos (Bartlett et al. 2011).

1.5 Determinación de la carga de entrenamiento

Es muy importante para los entrenadores conocer los ritmos de las corredoras *amateurs*, tanto para los entrenamientos como para las competiciones. Por este motivo, identificar estos registros es uno de los objetivos que se proponen en este estudio. Las variables fisiológicas de los corredores de larga distancia que podemos obtener en el laboratorio son esencialmente el VO_2max y otras variables.

El tiempo final de las carreras de fondo, como ya hemos citado en apartados anteriores, está altamente asociado a varios factores fisiológicos. En las pruebas de laboratorio podemos relacionar estrechamente la velocidad máxima alcanzada al finalizar la prueba con el rendimiento del atleta (Noakes et al. 1990, Knechtle et al. 2011, Ronconi y Alvero-Cruz 2011).

1.5.1 Pruebas de valoración funcional: Test

En nuestro estudio, el test utilizado en todo el control del entrenamiento fue el test de la Universidad de Montreal, UMTT (Leslie et al. 1999, Stutts 2002). Una prueba indirecta para estimar el VO_2max y la MAS, siendo uno de los más utilizados en la literatura científica para estimar estas variables, principalmente por el bajo error estándar de estimación (Léger and Boucher 1980) y la alta correlación entre las medidas obtenidas en el campo y en el laboratorio (Thébault et al. 2011).

La determinación de estas variables en un laboratorio no es un parámetro realista en el mundo del *running amateur*, puesto que los corredores no pueden realizar pruebas de laboratorio frecuentes para ajustar sus cargas de entrenamiento, por lo que recurrir a un test de campo hace que sean factibles de realizar para los atletas y para los entrenadores, siendo una buena elección para poder controlar las cargas de entrenamiento.

La aplicación del test de campo reduce la dependencia de equipamiento especializado y aumenta el número de sujetos que es posible evaluar en el mismo momento. Por lo tanto, el atleta y el entrenador pueden obtener una retroalimentación más regular y si el test utilizado es validado, pueden proporcionar una información similar a la obtenida con los test de laboratorio, siendo más específica. Aunque haya que ser cuidadoso en la realización para obtener una buena repetitividad en sus resultados.

El entrenamiento del medio maratón, requiere una evaluación específica de cara determinar el entrenamiento y poder garantizar que las cargas de trabajo aplicadas son las correctas. Teniendo en cuenta que hablamos de una prueba de larga distancia, estará determinada en gran medida por las variables del VO_2max y el coste energético del ejercicio.

1.6 Parámetros hematimétricos y biomarcadores

Los datos hematológicos y bioquímicos pueden servir a deportistas y entrenadores para tener información complementaria respecto al entrenamiento y la recuperación del mismo. Estos datos, junto a otros tests que podemos aplicar en el campo o en el laboratorio y el control del entrenamiento, nos ayudaran a completar un mejor trabajo como entrenadores.

1.6.1 Parámetros hematológicos

Entre los valores que suelen ser utilizados en distintos períodos del entrenamiento, está la realización de un hemograma completo. En el mismo, se analizan los glóbulos blancos (células relacionadas con el sistema inmunitario), los glóbulos rojos o hematíes (las células sanguíneas encargadas de transportar oxígeno unido a la hemoglobina de su interior) y las plaquetas (participantes en la coagulación). Se puede tener información de la concentración de hemoglobina, valor muy relacionado con la anemia, que en el grupo de población estudiado, mujeres deportistas con entrenamiento para competiciones de larga duración, puede tener una trascendencia en el rendimiento. Además, nos permite hacer un seguimiento a las adaptaciones como el aumento del volumen plasmático que se asocia a una disminución de los valores de hematíes que no tendremos que confundir con la disminución de este valor debido a un cuadro clínico de disminución del volumen absolutos de los hematíes circulantes.

Otros valores interesantes y relacionados con este hemograma es el hematocrito, un indicador de la cantidad relativa de glóbulos rojos circulantes en sangre. El volumen corpuscular medio (MCV) es el parámetro que indica el valor medio del volumen de cada hematíe; la hemoglobina corpuscular media (MCH) es el valor medio de hemoglobina que hay en cada hematíe. Finalmente, la concentración de hemoglobina corpuscular media (MCHC) es la concentración de hemoglobina por unidad de volumen de hematíes.

1.6.2 Concentraciones plasmáticas

El volumen plasmático se modifica con la realización de ejercicio, disminuyendo más cuanto más intenso es el ejercicio, produciendo cambios en los biomarcadores. Estas modificaciones están relacionadas con la sudoración o la hidratación (Bird et al. 2014, El-Sayed et al. 2005, Lippi et al. 2008). Pueden observarse modificaciones en algunos iones como el sodio (Na^+) que incrementa su concentración después del ejercicio (Bloomer and Farney 2013), y el cloro (Cl^-), cuya absorción está vinculada al Na^+. Mientras que los fosfatos disminuyen sus valores por el ejercicio.

La concentración de glucosa muestra una ligera tendencia a disminuir sus niveles en sangre en ejercicios prolongados por la depleción de las reservas de glucógeno hepático, cuando el ejercicio se mantiene en el tiempo, por encima de 1 h 30 min de duración (Bird et al. 2014), aunque compensada gracias a la neoglucogénesis.

1.6.3 Biomarcadores

Los marcadores biológicos o biomarcadores pueden permitir realizar una evaluación y un seguimiento del rendimiento deportivo, mostrando el efecto que tiene el deporte sobre distintos tejidos. Estos marcadores bioquímicos sanguíneos, ampliamente utilizados en deportes con necesidades metabólicas elevadas, expresan el estado inflamatorio, el posible daño oxidativo o la capacidad antioxidante.

1.6.3.1 Perfil lipídico y hepático

La proteína total, y la albúmina fundamentalmente, ayudan a mantener el equilibrio hídrico en la sangre y los tejidos, regulando el volumen plasmático.

Los valores lipídicos, como el colesterol total, engloban las lipoproteínas de baja densidad (LDL), las proteínas de alta densidad (LHD) y los triglicéridos (TAG) se pueden ver disminuidos como consecuencia de una adaptación al ejercicio (Costa et al. 2020).

Algunos marcadores relacionados con el daño hepático se midieron por primera vez en medio maratón en 2011 (Lippi et al. 2011) aportando que estos biomarcadores, en un contexto deportivo, podrían estar relacionados con el daño muscular. Así, del aspartato aminotransferasa (AST), alanina aminotransferasa (ALT) y la gamma-glutamil transpeptidasa (GGT) parece que no sufren variaciones significativas después de realizar este tipo de competición. Mientras que la bilirrubina total tiende a disminuir, pero también sin cambios significativos.

1.6.3.2 Marcadores de daño muscular e inflamación

Después de un ejercicio intenso y prolongado como es el medio maratón, se manifiesta un dolor muscular, que no es inmediato, si no que aparece unas 24-48 h después de haberse realizado, lo que conocemos como el dolor muscular de aparición tardía (DOMS) (MacIntyre et al. 1995, Lynn et al. 2018). El daño muscular tiene una respuesta inflamatoria que hace que aumenten las citoquinas, como la interlukina-6 (IL-6) (Stozer et al. 2020) o la proteína c-reactiva (CRP).

La IL-6 es una citoquina que puede desarrollar funciones inflamatorias o antiinflamatorias, siendo activada por el ejercicio físico, entre otros. Es la más abundante en la contracción muscular (Pedersen et al. 2001) y parece que podría ser de utilidad como un biomarcador potencial de sobreentrenamiento (Lee et al. 2017), habiendo una correlación entre el aumento de la intensidad del ejercicio y el aumento de la IL-6 (Ostrowski et al. 2000).

La CRP, ligada al aumento de la IL-6, se eleva cuando hay inflamación. Puede aumentar después de un ejercicio intenso, pero el ejercicio físico continuado en el tiempo hace que se reduzcan los valores basales. Cuando lo analizamos después de realizar un medio maratón, estos valores aumentan hasta 24 h post competición (Lynn et al. 2018).

La creatinquinasa (CK), un posible indicador de sobre-entrenamiento relacionado indirectamente con el DOMS, aunque también aumenta cuando hay roturas musculares, se eleva proporcionalmente a la intensidad o duración del ejercicio (Palacios et al. 2015, Braid 2012), pudiéndose constituir en un buen marcador de daño muscular (Gleeson 2002). Parece que este indicador alcanza los niveles más altos entre las 6-24 horas post ejercicio y recupera los valores normales entre las 48 y 72 horas tras el ejercicio (Brancaccio et al. 2006, Lynn et al. 2018) .

La aldolasa es una proteína que aumenta significativamente cuando hay daño muscular y que puede estar aumentada hasta 3 días después de realizar una prueba de larga duración (Tokinoya et al. 2020), relacionándose más con la duración que con la intensidad del ejercicio.

1.6.3.3 Marcadores de estrés oxidativo

Ya en 1978, se sugirió que el ejercicio físico podía producir daños en los tejidos a través de los radicales libres (Dillard et al. 1978). En los últimos años se han hecho varias revisiones para aumentar el conocimiento de la interferencia del estrés oxidativo con el ejercicio (Powers and Jackson 2008). Durante el ejercicio se aumentan la producción de radicales libres y especies reactivas de oxígeno (ROS), produciendo una situación de estrés oxidativo y desequilibrio de la homeostasis, conocido como *Redox Balance* (Kawamura and Muraoka 2018). Si hay un aumento importante de los niveles de ROS circulantes, se produce un aumento de la fatiga muscular por la disfunción contráctil del músculo esquelético (Powers and Jackson 2008). El organismo, ante el ejercicio, reacciona con sustancias antioxidantes enzimáticas: glutatión peroxidasa (GP_X), superóxido dismutasa (SOD), glutatión reductasa (GR); y con glutatión: glutatión en estado reducido (GSH) o glutatión oxidado (GSSG).

Así pues, en la presente tesis, se analizarán dos apartados, por un lado, el efecto del entrenamiento respecto a parámetros funcionales y cardio respiratorios; y por otro lado, el efecto del entrenamiento a través del rendimiento obtenido en todo el proceso de entrenamiento y en el medio maratón juntamente con el efecto que este ha causado a nivel sanguíneo y de marcadores de daño muscular, inflamación y estrés oxidativo.

2

Objetivos

Hasta la actualidad, son escasos los estudios relacionados con mujeres corredoras *amateurs* en edad media, la hipótesis de la presente tesis es que realizar un estudio con este grupo poblacional podría aportar más información, precisa y novedosa. Con ella, se podría intentar adaptar el entrenamiento a las necesidades y actividades diarias de este grupo de población, que muy a menudo no dispone de suficiente tiempo como para poder prepara una prueba de estas características para afrontarla de manera competitiva.

2.1 Objetivo general

Comparar dos programas de entrenamiento para preparar un medio maratón en mujeres con una edad media de 40 años, valorando el efecto sobre el rendimiento deportivo (tiempo en el medio maratón) y diversos parámetros fisiológicos.

2.2 Objetivos específicos

- Diseñar y validar un programa de entrenamiento *amateur* alternativo, basado en una planificación de cargas de trabajo físico en la que la intensidad del esfuerzo predomine por encima del volumen de carrera.

- Obtener una fórmula que permita estimar el VO_2max en el campo de manera indirecta a partir del test UMTT, con la finalidad de poder programar las cargas de entrenamiento y realizar su seguimiento.

- Evaluar y comparar el VO_2max e indicadores de capacidad y potencia aeróbica durante el test progresivo de Léger, realizado en el laboratorio, entre los dos programas de entrenamiento evaluados.

- Valorar la homogeneidad en la respuesta al entrenamiento entre las participantes en el estudio, valorando las diferencias , entre los dos programas de entrenamiento evaluados.

- Evaluar y comparar parámetros hematológicos y plasmáticos indicadores del transporte de oxígeno y de estrés fisiológico, en los dos programas de entrenamiento evaluados, después de los protocolos de entrenamiento (y antes del medio maratón) y 24 horas después de la finalización del medio maratón.

- Realizar un seguimiento de parámetros de bienestar como la calidad del sueño y la percepción del esfuerzo a lo largo de los meses de entrenamiento, entre los dos programas de entrenamiento evaluados.

3

Informe del director

3 INFORME DEL DIRECTOR

Los doctores Casimiro Javierre, José Magalhães y Joan Ramon Torrella, como directores de la Tesis Doctoral presentada por Jèssica Bonet Bonet, hacen constar que la doctoranda ha participado activamente en la elaboración de los artículos que forman esta memoria, tal como queda reflejado en el orden y la composición del conjunto de autores en cada uno de ellos. La doctoranda ha jugado un papel clave en el diseño experimental, en la obtención de datos, en su tratamiento estadístico y ha participado activamente en el razonamiento de los resultados de la totalidad de los estudios que constituyen el núcleo de su tesis. También ha asumido el protagonismo en la presentación de los avances de los estudios en diversos congresos y reuniones científicas y en la redacción de los manuscritos.

Los detalles de las publicaciones que se han aceptado o se hallan en evaluación editorial de los artículos que conforman esta tesis son los siguientes:

Artículos publicados

I. Título de la publicación: A Field Tool for the Aerobic Power Evaluation of Middle-Aged Female Recreational Runners.

   Autores (p.o. de firma): Bonet JB, Magalhães J, Viscor G, Pagès T, Javierre CF, Torrella JR.

   Año: 2020.

   Revista: Women and Health.

   DOI: 10.1080/03630242.2020.1746953

   Volumen: 60 Número: 7 Páginas: 839-848 ISSN: 0363-0242

   Editorial: Routledge Journals Taylor and Francis. USA.

   Participación de la doctoranda: diseño experimental, obtención y valoración de los datos, redacción del borrador y su aprobación final.

   IF en JCR (2019): 1.095.

Rango (2019): 23/45 (T2 – Women's Studies).

II. Título de la publicación: High-Intensity Interval versus Moderate-Intensity Continuous Half-Marathon Training Programme for Middle-Aged Women.

Autores (p.o. de firma): Bonet JB, Magalhães J, Viscor G, Pagès T, Javierre CF, Torrella JR.

Año: 2020.

Revista: European Journal of Applied Physiology.

DOI: 10.1007/s00421-020-04347-z.

Volumen: 120 Páginas: 1083–1096 ISSN: 1439-6319

Editorial: Springer-Verlag GmbH. Alemania.

Participación de la doctoranda: diseño experimental, obtención y valoración de los datos, redacción del borrador y su aprobación final.

IF en JCR (2019): 2.580.

Rango (2019): 28/85 (T1 – Sports Sciences).

III. Título de la publicación: Inter-individual different responses to continuous and interval training in recreational middle-aged women runners.

Autores (p.o. de firma): Bonet JB, Magalhães J, Viscor G, Pagès T, Ventura JL, Torrella JR, Javierre C.

Año: 2020.

Revista: Frontiers in Physiology.

DOI: 10.3389/fphys.2020.579835

Volumen: 15 Número artículo: 579835 ISSN: 1664-042X

Editorial: Frontiers Media. Suiza.

Participación de la doctoranda: diseño experimental, obtención y valoración de los datos, redacción del borrador y su aprobación final.

IF en JCR (2019): 3.367.

Rango (2019): 20/81 (T1 – Physiology).

Artículo sometido a revisión editorial

IV. Título de la publicación: Haematological and biochemical parameters in middle-aged women after a half marathon trained with a volume- or intensity-based program.

Autores (p.o. de firma): Bonet JB, Javierre C, Rizo-Roca D, Beleza J, Viscor G, Pagès T, Magalhães J, Torrella JR.

Año: 2020.

Revista: Medicine and Science in Sports and Exercise.

DOI: N/A

Editorial: Lippincott Williams & Wilkins. USA.

Participación de la doctoranda: obtención y valoración de los datos, aprobación final del manuscrito.

IF en JCR (2019): 4.029.

Rango (2019): 9/85 (T1 – Sports Sciences).

Artículo relacionado colateralmente con la tesis doctoral pero que no forman parte de ella:

1. Título de la publicación: Contractile Activity Is Necessary to Trigger Intermittent Hypobaric Hypoxia-Induced Fiber Size and Vascular Adaptations in Skeletal Muscle.

Autores (p.o. de firma): Rizo-Roca D, Bonet JB, Ínal B, Ríos-Kristjánsson JG, Pagès T, Viscor G, Torrella JR

Año: 2018.

Revista: Frontiers in Physiology.

DOI: 10.3389/fphys.2018.00481

Volumen: 9 Número artículo: 481 ISSN: 1664-042X

Editorial: Frontiers Media. Suiza.

Participación de la doctoranda: obtención y valoración de los datos.

IF en JCR (2018): 3.201.

Rango (2018): 25/81 (T1 – Physiology).

Resultados preliminares presentados en congresos:

1. Título de la comunicación: Using time to exhaustion in the Université de Montréal track test to evaluate maximum oxygen uptake in the track field for female master recreational runners.

   Autores (p.o. de firma): Bonet JB, Javierre C, Alamo J, Viscor G, Pagès T, Magalhães J, Torrella JR.

   Año: 2016.

   Tipo de comunicación: Póster.

   Congreso: 21st Annual Congress of the European College of Sport Science (ECSS).

   Localidad: Viena (Austria).

2. Título de la comunicación: Haematological parameters in middle-aged amateur female runners following two different schedule training for a half-marathon run.

   Autores (p.o. de firma): Torrella JR, Bonet JB, Alamo J, Mancera EM, Ramos DM, Rizo D, Pagès T, Viscor G, Magalhães J, Javierre C.

   Año: 2016.

Tipo de comunicación: Póster.

Congreso: 21st Annual Congress of the European College of Sport Science (ECSS).

Localidad: Viena (Austria).

3. Título de la comunicación: Comparació de l'eficàcia d'un model d'entrenament de mitja marató basat en la intensitat i l'entrenament de força davant d'un model clàssic basat en el volum de carrera.

   Autores (p.o. de firma): Bonet JB.

   Año: 2018.

   Tipo de comunicación: Oral.

   Congreso: III Workshop Internacional la Igualdad en juego.

   Localidad: Barcelona (España).

4. Título de la comunicación: Evaluation of an intensive versus extensive half-marathon schedule training for middle-aged amateur female runners.

   Autores (p.o. de firma): Bonet J, Torrella JR, Magalhães J, Viscor G, Pagès T, Javierre C.

   Año: 2019.

   Tipo de comunicación: Póster.

   Congreso: 24th Annual Congress of the European College of Sport Science (ECSS).

   Localidad: Praga (República Checa).

4

Publicaciones

Artículo I

Bonet JB, Magalhães J, Viscor G, Pagès T, Javierre CF, Torrella JR (2020) A Field Tool for the Aerobic Power Evaluation of Middle-Aged Female Recreational Runners. *Women & Health* 60(7), 839-848.

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A field tool for the aerobic power evaluation of middle-aged female recreational runners

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ABSTRACT

This study used time to exhaustion (TTE) to predict $\dot{V}O_{2max}$ in female recreational master runners. Forty-two middle-aged women (mean = 40.5 ± 5.9 years) who had trained for recreational running performed two *Université de Montréal* Track Tests in the facilities of the University of Barcelona (Spain). The first was performed on a treadmill (t), the second, on an athletics track (field: f). After measuring TTE and $\dot{V}O_{2max}$ on the treadmill, a first-order equation was obtained to estimate $f\dot{V}O_{2max}$ from fTTE. No significant difference was observed between the estimated $f\dot{V}O_{2max}$ (46.5 ± 2.9 mL·kg^{-1}·min^{-1}) and the measured $t\dot{V}O_{2max}$ (46.2 ± 5.3), with a mean value of the absolute differences of less than 8% of the $t\dot{V}O_{2max}$ average. High agreement between the two $\dot{V}O_{2max}$ values was also evident, as shown by the low bias of the differences and the Bland-Altman plot. The equation obtained is of interest to evaluate performance in middle-aged female recreational runners. It will allow coaches and runners to set running paces for training and could be used in training routines to determine improvements after a training program. Moreover, these tools could be used in the field to assess the physical fitness of middle-aged women, in efforts to preserve their health and physical function.

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Since the pioneering studies by Hill and coworkers in the 1920s (Hill, Long, and Lupton 1924; Hill and Lupton 1922), exercise physiology researchers have paid considerable attention to maximal oxygen consumption ($\dot{V}O_{2max}$), being this parameter one of the most studied in sports physiology. A good definition would consider $\dot{V}O_{2max}$ to be the maximal integrated capacity of the pulmonary, cardiovascular and muscle systems to uptake, transport and consume oxygen per unit of time (Poole, Wilkerson, and Jones 2008). Although there are many variables affecting aerobic exercise performance, assessing $\dot{V}O_{2max}$ is still used for testing the efficacy of training strategies. To obtain $\dot{V}O_{2max}$ it is necessary to use a gas analyzer, which poses serious logistical drawbacks and increases costs if it is intended to obtain the measure in the field. For this reason, it is very useful to perform indirect testing to

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estimate $\dot{V}O_{2max}$ in the field. The *Université de Montréal Track Test* (UMTT) (Léger and Boucher 1980) is the most often used and recommended test in the scientific literature to estimate $\dot{V}O_{2max}$ together with other common measurements to evaluate endurance exercise, such as the maximal aerobic speed (MAS), defined as the maximum velocity sustained for 2 minutes during a UMTT (Billat et al. 1996), and the time to exhaustion (TTE), time after which the individual can no longer maintain the pace of the treadmill (see for example, Kaynak et al. 2017). Higher MAS and longer TTE, have been considered important factors that improve aerobic endurance (see for example, Bangsbo et al. 2009).

According to Haskell et al. (2007) updating report on Physical Activity and Public Health guidelines given by the American College of Sports Medicine and the American Heart Association, to promote and maintain health aerobic exercise of moderate intensity is recommended for all healthy adults aged 18 to 65 for a minimum of 30 min on five days each week. Fortunately, many people already acknowledge the health benefits of endurance training and, since the 1960 s, running has increased in popularity as an amateur sport that is performed as a health or leisure activity with no competitive aim (van Dyck et al. 2017). Running events, such as road or urban races of different distances have grown in participation over the last few decades, with women aged between 25 and 44 accounting for a significant proportion of finishers in USA (Running USA 2017). These figures should be seen as good news from the women's health point of view, since a recent study conducted out on women aged 65 to 70 years (Edholm, Nilsson, and Kadi 2019) has demonstrated that engagement throughout adulthood in sports activities from moderate to high intensity (such as running) improved physical function at old age. However, the appearance of large amounts of people involved in recreational running has posed some important inconveniencies in several aspects of training, which are concomitant with the increase of injuries due to inadequate training schedules or training burden (Nielsen et al. 2013). For this reason, it could be important for all recreational runners, and for middle-aged women in particular, to follow customized training programs where pacing rhythms, training volumes and intensity loads could be properly addressed during leisure running and racing preparation periods.

The purpose of this study was to verify the use of TTE in the UMTT to predict $\dot{V}O_{2max}$ for female master recreational runners on the track and field. We developed an equation, derived from a protocol consisting of a widely used track test (UMTT), that correlates TTE and $\dot{V}O_{2max}$ in the field and may have practical application for a very specific group of population: middle-aged (around 40 years old) female Caucasian runners training at recreational levels. To focus on female population groups is important because there has been a recent increase in middle-aged females that take part in recreational running and races (Wilder 2014) and also because there is a gap in the literature on female runner's studies, such as those focused on performance prediction and running-related injuries (Gijon-Nogueron et al. 2019). We hypothesize that $\dot{V}O_{2max}$ could be predicted in the field for this specific population group after an easy-measurable and simple parameter (TTE), using a mathematical approach obtained from the UMTT in a laboratory treadmill.

Methods

Participants

Forty-two middle-aged women volunteered to participate in the study. All participants were selected from an initial sample of 46 women recruited from five running clubs settled in the city of Barcelona (Spain). To select the participants, the recruiting was done by means of an initial questionnaire and the screening after personal interviews. During this selection process, the following eligibility criteria were considered. Women must be pre-menopausal, with an age range between 35 and 45 years, to have no injuries, not to take any medication and to be nonsmokers. They must have a minimum of two years' experience in popular recreational running competitions, such as 10-km courses and half-marathons, and training routines of at least 3 sessions per week including 1 hour per session. The initial sample (n = 46) was reduced to the final sample (n = 42) due to the abandonment of four participants for personal reasons, giving thus a final participation rate of 91%.

The study was developed in accordance with the Helsinki Declaration concerning the ethical principles of human experimentation and approved by our Institutional Ethical Committee (Institutional Review Board number IRB00003099), in accordance with current Spanish legislation. The participants were informed about and familiarized with all the experimental procedures, as well as their risks and benefits. They signed an informed consent form and were free to withdraw from the experimental protocol at any time.

Experimental Approach

Participants in the study performed two UMTTs following the original Léger and Boucher (1980) protocol. All data were collected between September 4th and October 21th, 2016. The first test was performed on a treadmill in the laboratory of Exercise Physiology (Faculty of Health Sciences and Medicine, University of Barcelona, Spain); the second, on an outdoor athletics track in the facilities of the Sports Service of the University of Barcelona (Spain). The $\dot{V}O_{2max}$ was obtained on the treadmill, and the MAS, TTE and heart rate (HR) were recorded in both tests. After testing the correlation of TTE with the $\dot{V}O_{2max}$ obtained in the laboratory, we proposed an equation to estimate $\dot{V}O_{2max}$ in the field for middle-aged amateur women runners. The dependent variable was the field $\dot{V}O_{2max}$ and the independent variable was the TTE obtained in the field. TTE was chosen instead of MAS, which was used in the original method, because it is easier to measure in the field.

Procedures

Experimental design and procedures in the laboratory

The participants performed a UMTT (Léger and Boucher 1980) in the laboratory on a treadmill (Quasar h/p Cosmos® Sports and Medical GmbH, Nussdorf-Traunstein, Germany). Following the original Léger and Boucher (1980) protocol, the test started with a four-minute warm-up beginning at a speed of 6 $km{\cdot}h^{-1}$ and increased by 1 $km{\cdot}h^{-1}$ every two minutes, with a slope of 0.6%. After the four-minute warm-up, the test continued with further increases of 1 $km{\cdot}h^{-1}$ every two minutes until exhaustion. During the test, heart rate (HR), treadmill $\dot{V}O_{2max}$ ($t\dot{V}O_{2max}$), treadmill TTE (tTTE) and MAS were measured. The HR was monitored using CardioScan v.4.0, DM Software (Stateline, Nevada, USA) and $t\dot{V}O_{2max}$ was measured with an automatic gas analysis system pneumotachometer (TR-plus Metasys, Brainware SA, La Valette, France) equipped with a two-way mask (Hans Rudolph, Kansas, USA). Gas and volume calibrations were performed before each test, according to the manufacturer's instructions. MAS was recorded either as the speed of the last completed stage; or, if a stage was started but not completed, then as the speed during the previous stage plus 0.5 $km{\cdot}h^{-1}$ (Meyer et al. 2003).

Experimental design and procedures in the field

Forty-eight hours after completing the laboratory test, the participants performed the UMTT in the field, on an official athletics track. The field test was divided into the same phases and performed under the same conditions as the laboratory test. The speed of each stage was controlled by sound signals from a computer connected to a loudspeaker system, while the track was marked with cones every 50 meters; at each sound signal, the participants had to be passing by the cones. The test finished when the participant could no longer maintain the speed required, and the field TTE (fTTE) was then recorded. During the test, HR was recorded using a Suunto Ambit3 Sport© heart rate monitor (Suunto Oy, Vantaa, Finland).

Statistical Analysis

The normality and homoscedasticity of the data were tested using Shapiro-Wilk's and Levene's tests, respectively, considering that the tests were not passed when $p < .05$. Linear regression and the Pearson's Product Moment test were applied to demonstrate the correlation between fTTE and both tTTE and $t\dot{V}O_{2max}$. This latter correlation was used to estimate the value of $f\dot{V}O_{2max}$ from the fTTE values by means of a first-order equation. The different parameters obtained on the treadmill and in the field are expressed as mean ± standard deviation of the mean (SD) and were compared using paired t-tests. Statistical significance was established at the level of $p < .05$. To assess the magnitude of the differences between tests, the complimentary analysis of Cohen's *d* effect size index was calculated by dividing the difference between the group means by the standard deviation (Sullivan and Feinn 2012). The mean of the absolute differences (MAD) between the measured $t\dot{V}O_{2max}$ and the estimated $f\dot{V}O_{2max}$ values was calculated using the equation (McGraw and Wong 1994):

$$MAD = \frac{1}{N}\sum_{i=1}^{N}|xt_i - xf_i|$$

where xt and xf were the experimental $\dot{V}O_{2max}$ values obtained on the treadmill and the estimated $\dot{V}O_{2max}$ field values, respectively. A Bland-Altman plot was created to visually represent and test the limits of agreement between fTTE and $t\dot{V}O_{2max}$ correlated in the first-order equation. For all the statistics, α was set to 0.05. All statistical tests were run using SigmaPlot® 11.1 (Systat Software Inc., San Jose, CA, USA).

Results

All the participants were adult women with a mean age of 40.5 years, mean BMI of 21.5 ± 2.4 $kg{\cdot}m^{-2}$, mean percent body fat of 23.7 ± 5.4%, and mean percent muscle mass of 43.3 ± 3.4% (Table 1). The participants showed significantly higher HR after finishing the field test and also needed more time to reach exhaustion than when on the treadmill, whilst no significant difference was observed between the two MAS values (Table 2). Effect size index values were small ($d < 0.5$) in all cases indicating that the statistical differences from p-values near to $p = .05$ should be taken with caution.

The correlation between TTEs obtained on the treadmill (tTTE) and in the field (fTTE) was statistically significant ($p < .001$), with a Pearson's correlation coefficient of r = 0.93. After this, the correlation between fTTE and $t\dot{V}O_{2max}$ was studied to obtain an equation to estimate $f\dot{V}O_{2max}$ from fTTE. The linear regression between fTTE and $t\dot{V}O_{2max}$ was statistically significant ($p < .001$) with a Pearson's correlation coefficient of r = 0.71 (Figure 1). Thus, the first-order equation obtained to estimate $f\dot{V}O_{2max}$ ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$) from fTTE (seconds) was:

$$f\dot{V}O_{2\,max} = 21.244 + 0.0262 \cdot fTTE$$

When comparing $t\dot{V}O_{2max}$ and the estimated $f\dot{V}O_{2max}$ by means of a paired t-test, no statistical differences were found ($p = .70$, Table 2), with a MAD between the measured $t\dot{V}O_{2max}$ and the estimated $f\dot{V}O_{2max}$ values of 3.7 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$. Figure 2 shows the Bland-Altman plot with the bias (0.025), and lower (−7.42) and upper (7.47) limits of agreement.

Discussion

This study was aimed to obtain a mathematical tool to be applied to middle-aged female runners which could predict the $\dot{V}O_{2max}$ by using the TTE in the field. We believe that our initial hypothesis can be accepted since a first order equation correlating TTE and $\dot{V}O_{2max}$ in the field with a reasonable level of statistical accuracy is given after the data obtained from UMTTs performed in the laboratory in a sample of forty-two women. This tool could contribute to middle-aged women's health in the assessment and prescription of recreational training, reducing the likelihood of injuries and improving the women's fitness.

Table 1. Anthropometric data for the study participants (Mean ± Standard Deviation).

Anthropometric parameter	Mean ± sd (n = 42)
Age (years)	40.5 ± 5.9
Weight (kg)	58.3 ± 7.3
Height (cm)	167.0 ± 6.0
BMI ($kg{\cdot}m^{-2}$)	21.5 ± 2.4
% Fat	23.7 ± 5.4
% Muscle mass	43.3 ± 3.4

BMI = body mass index.

Table 2. Mean values (± Standard Deviation) measured both on the treadmill and in the field.

	Treadmill	Field	p-value	Effect size (d)
MAS ($km{\cdot}h^{-1}$)	13.2 ± 1.1	13.5 ± 1.1	.070	0.276
TTE (sec)	974 ± 136	991 ± 141	.038	0.124
HR (bpm)	175 ± 10	179 ± 10	.027	0.367
$\dot{V}O_{2max}$ ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	46.2 ± 5.3	46.5 ± 2.9	.704	0.067

HR = heart rate; MAS = maximal aerobic speed; TTE = time to exhaustion; $\dot{V}O_{2max}$ = maximal oxygen consumption. The field $\dot{V}O_{2max}$ value was estimated using the formula. The p-value shown was obtained after applying a paired t-test.

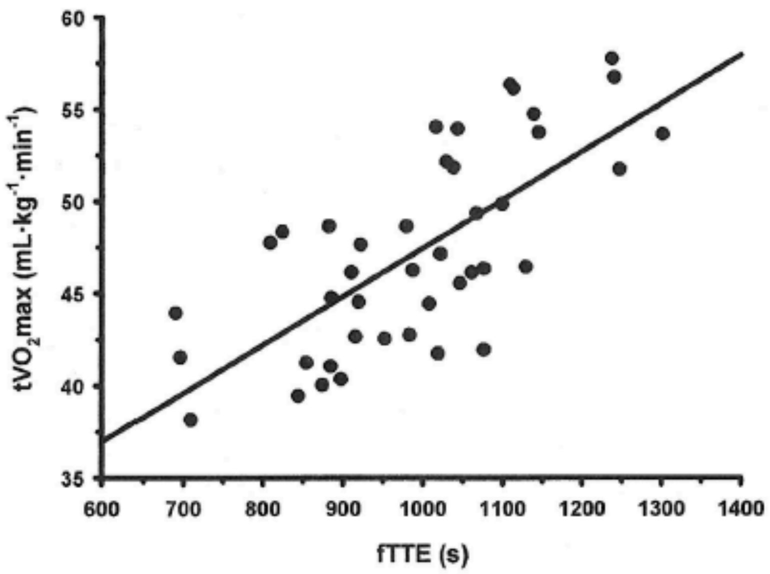

Figure 1. Relationship between fTTE and t$\dot{V}O_{2max}$. The linear correlation was statistically significant ($p < .01$) with r = 0.708.

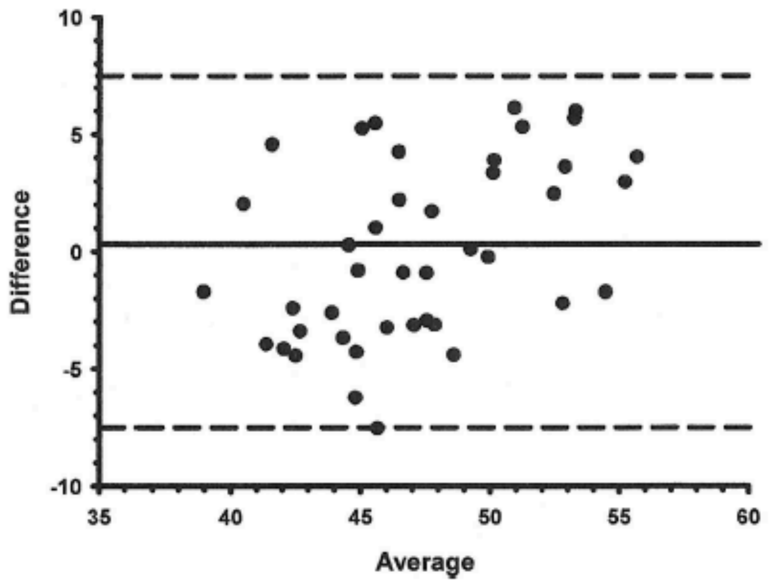

Figure 2. Bland-Altman Plot of t$\dot{V}O_{2max}$ and the (estimated) f$\dot{V}O_{2max}$ values. Dashed lines are the lower (−7.42) and upper (7.47) limits of agreement. The solid line is the mean of the differences (0.025) with SD = 3.80.

The evaluation of a runner's performance by applying physical tests is useful to monitor training progress and prescribe training intensities. Assessing a runner's $\dot{V}O_{2max}$ can assist in achieving adequate planning of training to enhance field performance. However, sophisticated laboratory devices (gas analyzers and a treadmill) or expensive portable field equipment are needed to obtain an individual's $\dot{V}O_{2max}$ (Billat et al. 1996). The UMTT (Léger and Boucher 1980) is a well-known progressive incremental field test for runners. Many studies have used this test to calculate $f\dot{V}O_{2max}$ from MAS obtained on an outdoor track for populations of young, mainly male, trained athletes (see for example, Llodio et al. 2016; Lopes et al. 2016). Nevertheless, TTE is easier to measure in the field than MAS, which led us to consider the suitability to present a simple first-order equation to estimate $f\dot{V}O_{2max}$ from fTTE intended to be applied to a very specific population: female recreational runners aged 35 to 45.

The equation was obtained after checking the linear correlation between fTTE and both tTTE ($p < .001$) and $t\dot{V}O_{2max}$ ($p < .001$); see Figure 1. Thus, measuring fTTE in seconds allows us to estimate $f\dot{V}O_{2max}$ in $mL{\cdot}kg^{-1}{\cdot}min^{-1}$. The usefulness of the equation as a prediction model is supported by three pieces of evidence: (1) no statistical differences ($p = .70$) were apparent between the predicted $\dot{V}O_{2max}$ in the field and the $\dot{V}O_{2max}$ obtained in the laboratory (Table 2); (2) the mean value of the individual absolute differences between the measured $t\dot{V}O_{2max}$ and the estimated $f\dot{V}O_{2max}$ was less than 8% of the $t\dot{V}O_{2max}$ average; and (3) treadmill and field $\dot{V}O_{2max}$ values were in high agreement, as shown by the low bias of the differences and the fact that all the points in the Bland-Altman plot (Bland and Altman 1986) lie inside the limits of agreement (Figure 2).

Field $\dot{V}O_{2max}$ was achieved at the same MAS ($p = .070$, $d = 0.276$) with prolonged TTE and increased HR (Table 2), compared to the $\dot{V}O_{2max}$ obtained in the laboratory. These results agree with those found in heterogeneous male populations (McMiken and Daniels 1976; Meyer et al. 2003), in which no differences were reported in $\dot{V}O_{2max}$ between direct measures, obtained both in the laboratory and the field (using portable gas analysis devices). However, p-values for TTE and HR had magnitudes near to $p = .05$ with small effect size index values ($d < 0.5$) (Table 2) indicating that the statistical differences from p-values should be taken with caution (Sullivan and Feinn 2012). Although the characteristics and the sizes of the samples are very different, the absence of statistical differences in MAS between field and treadmill tests found in middle-aged women are in agreement with the results reported by Berthoin et al. (1999) for adolescent boys and girls, and also with those presented by De Souza et al. (2014) in moderately trained runners. In slight contrast, Lacour et al. (1991) reported, for a UMTT in a group of well-trained runners of both sexes, that velocity at $\dot{V}O_{2max}$ was also slightly higher in the field (6.08 ± 0.41 $m{\cdot}s^{-1}$) than in the laboratory (6.01 ± 0.44 $m{\cdot}s^{-1}$). Also Meyer et al. (2003) reported, in male subjects, improved running economy in the field with higher MAS and longer exercise duration (TTE). Nevertheless, most studies of $\dot{V}O_{2max}$ in the field have been performed on men (McMiken and Daniels 1976; Meyer et al. 2003) and, when women are included, they are usually either well-trained athletes (Hagan et al. 1987; Lacour et al. 1991; Snoza, Berg, and Slivka 2016) or young individuals (Berthoin et al. 1999). To our knowledge, only the study by Machado et al. (2011) reported $\dot{V}O_{2max}$ data obtained in the field for middle-aged (42.2 ± 7.5 years) female recreational runners.

In the original paper where the basis of the UMTT was established, Léger and Boucher (1980) presented a second-order equation, allowing the energy cost of horizontal running in the field to be calculated using the speed of running. When considering MAS, that equation allowed the estimation of $f\dot{V}O_{2max}$ Léger and Boucher (1980) demonstrated a very good correlation (r = 0.96) between the predicted $f\dot{V}O_{2max}$ and the direct

$t\dot{V}O_{2max}$. To establish their equation, they used a heterogeneous population of 6 untrained and 9 trained men, aged 35.2 ± 3.7 and 22.0 ± 3.8 years, respectively. Thus, what we present here is a simple first-order equation to estimate $f\dot{V}O_{2max}$ using fTTE instead of MAS, to be applied to middle-aged female recreational runners. In our opinion, this population group is likely to behave differently from others, because sex-based differences in substrate metabolism during endurance exercise are well-known (Gui et al. 2017), and changes in maximal aerobic capacity with age, specifically in middle-aged women, have also been reported (Eskurza et al. 2002). Using MAS from our female participants as x in the Léger and Boucher equation ($y = 14.49 + 2.143x + 0.0324x^2$), we obtained an estimated $y = f\dot{V}O_{2max}$ with a mean value of 49.1 ± 3.4 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ which is significantly different (p < .001) from the estimated $f\dot{V}O_{2max}$ obtained from our equation (46.5 ± 2.9 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$). The fact that the original equation was obtained from young men and the equation presented here from middle-aged women would explain the lower mean $\dot{V}O_{2max}$ value using our equation.

Given these differences and the increasing social interest that amateur running is gaining among women, the equation presented here would be of interest when using the UMTT to evaluate aerobic fitness in the field in a particular population group: middle-aged female recreational runners. There are other variables, such as the ventilatory threshold and the running economy, that have greater explanatory power than $\dot{V}O_{2max}$ in evaluating running performance. Although these variables are also very sensitive to training effects and very consistent for training prescription, there are difficulties to measure them in the field (Saunders et al. 2004). Thus, although having some limitations, the equation we are presenting for women's amateur running $f\dot{V}O_{2max}$ evaluation will be a useful tool to be used together with the follow-up of the performance results. The main limitation of the study derives from the combination of two facts that could have rendered some dispersion in the measures obtained: the sample size (n = 42) and the variability between the training status of the different participants. Moreover, the select nature and lack of representativeness of the sample could reduce the generalizability of the results. Thus, the level of recreational training must be taken into consideration when using the equation.

In conclusion, an equation that may have practical application to determine the effort intensity intended for the prescription of running training for middle-aged female derived from an indirect protocol is given. The equation will enable to estimate $\dot{V}O_{2max}$ in the field from the measure of the time to exhaustion and could be used in training routines to determine whether real changes occur after a training program. Moreover, this tool would be able to assess in the field the physical fitness of middle-aged women, joining efforts aimed to preserve their health and physical function when reaching the old age.

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Disclosure statement

Authors disclose all and any potential conflict of interest.

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Artículo II

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ORIGINAL ARTICLE

High-intensity interval versus moderate-intensity continuous half-marathon training programme for middle-aged women

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Abstract

Purpose To test the effectiveness on recreational female middle-aged runners of a programme of high-intensity interval training (HIIT) for a half-marathon race contrasted to a conventional moderate-intensity continuous training (MICT).

Methods Twenty recreational female runners (40 ± 7 years) followed MICT or HIIT schedules for training a half-marathon. The MICT group trained a mean of 32 km/week at intensities below 80% VO_2max. The HIIT group ran 25 km/week at intensities between 80 and 100% VO_2max, combined with uphill running and resistance training. Women following HIIT ran 21% less distance and invested 17% less time than those from MICT group. All the women were evaluated at the beginning and end of the training and participated in the same half-marathon run.

Results Women following both schedules reduced their previous finishing times by 2–3%, which for HIIT group would have meant rising up to 90 positions out of 1454 participants in the local half-marathon race. The high intensity performed during series of high power output (200 m and 400 m) and resistance sessions in HIIT programme promoted changes that allowed modifying efficiency at high workloads. At the same time, the HIIT training programme elicited changes in oxygen uptake and transport as indicated the cardiorespiratory parameters obtained during recovery in lab tests. Moreover, HIIT registered a 14% baseline decrease in heart rate contrasting to the not significant 6% decrease in MICT.

Conclusions Runners following HIIT training obtained similar registers as with a traditional MICT schedule, expending less time and running shorter distances, yet improving their anaerobic and aerobic power.

Keywords Women · Half-marathon · High-intensity interval training · Moderate-intensity continuous training · Aerobic performance

Abbreviations

F-TE	Field time to exhaustion
F-UMTT	Field University of Montreal Track Test
FR	Fast run
HIIT	High-intensity interval training
HR	Heart rate
IR	Interval running
L-TE	Laboratory time to exhaustion
L-UMTT	Laboratory University of Montreal Track Test
LR	Long distance running
MM	Magic mile test
MICT	Moderate-intensity continuous training
O_2Pulse	Oxygen pulse
RPE	Rating of perceived exertion
RR	Respiration rate
SD	Standard deviation
UH	Uphill run
VCO_2	Carbon dioxide output
V_E	Respiratory minute volume

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Casimiro Javierre and Joan R. Torrella have contributed equally.

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VO_2	Oxygen uptake
VO_2max	Maximal oxygen uptake
V_T	Tidal volume
WE	Own body weight resistance exercises

Introduction

Participation in half-marathon events has increased over recent decades, with numbers of finishers growing every year. For example, in the USA, the number of half-marathon finishers increased from ≈ 300,000 to ≈ 1,900,000 in 2016 (Running USA 2017). Also, in Europe, a thorough study of data from all half-marathons held in Switzerland from 1999 to 2014, reported an increase from 7767 to 454,352 finishers (Knechtle et al. 2016). These sources also reported that the highest increases were registered in female runners, where most finishers were recorded as being in the 40–44 years age group. Thus, considering the importance of half-marathons in recreational sport and the gender and age characteristics of a substantial number of practitioners, it could be beneficial to optimise specific training schedules for women in their 40s. To our knowledge, only a few recent studies on half-marathon training include this demographic group (Lanier et al. 2012; Knechtle et al. 2014; Damsted et al. 2019). In our opinion, given declines reported in exercise training "stimulus" (intensity, duration and frequency) with advancing age in women (Tanaka et al. 1997), the increases in job- and family-related responsibilities (Tanaka and Seals 2008) and the greater risks that middle-aged women have of half-marathon-related injuries than men (Mohseni et al. 2019), the training schedule for master recreational women should be focused on reducing physiological stress, favouring the adjustment of training to job and family life and helping to reduce the risk of injuries.

The classic doctrine of training for races involving long distances, such as the half-marathon, is that the training schedule focuses on great running volume (Hagerman 2005; Hamilton and Sorace 2018). High volumes of endurance training imply the investment of a considerable amount of time. Since lack of time is the most commonly reported factor in the abandonment of training schedules (Weinberg and Gould 2011), protocols involving a combination of intense and endurance exercise periods could be an alternative. High-intensity interval training (HIIT), with schedules that intersperse sets of short duration with periods of recovery, is a powerful stimulus for inducing both central (cardiovascular) and peripheral (skeletal muscle) adaptations, leading to improved exercise capacity (Gibala and McGee 2008; Iaia and Bangsbo 2010; Gibala et al. 2012). After HIIT schedules, there have been reported increases in skeletal muscle mitochondrial biogenesis resulting in a more oxidative phenotype comparable to those induced by moderate-intensity continuous training (MICT) (Gibala et al. 2006; Burgomaster et al. 2008; Fiorenza et al. 2018). Thus, several HIIT running training programmes have been tested over the last decade resulting in effective fitness adaptations despite the lower volume of total exercise performed (see for example, Lanier et al. 2012; Hazell et al. 2014; McEwan et al. 2018).

The aim of our study was to determine the effects of two training programmes for a half-marathon, to be applied to middle-aged women normally engaging in recreational running. A programme with HIIT sessions of 40–90 s and short recovery periods interspersed with low volume endurance sessions was contrasted with a traditional training programme based on high volume of MICT. We hypothesize that the alternative HIIT programme will achieve at least the same performance results as those obtained after the MICT programme, involving less training volume and time, thus facilitating easier reconciliation of half-marathon preparation with daily life.

Methods

Participants

All participants were healthy female master recreational runners aged 40 ± 7 years recruited from five running clubs settled in the city of Barcelona (Spain). An initial questionnaire and screening after personal interviews were used to assess the following eligibility criteria. Women must be pre-menopausal, with an age range between 35 and 45 years, to have no injuries, not to take any medication (including oral contraceptives) and to be non-smokers. They must have a minimum of 2-year experience in popular recreational running competitions, such as half-marathons, training a minimum of 3 days and more than 5 h per week. We powered the sample size on the variable finishing time to fit power parameters of $\alpha = 0.05$ and $\beta = 0.20$, estimating both the size of the change to be detected and the size of the standard deviation change as 0.05. With these constraints, the minimum sample size for t paired tests (comparing previous finishing times versus finishing times after each training programme) was set at $n = 10$. However, since the recruitment procedure allowed selecting an initial sample of 22 participants, the study began with 11 participants per group.

Participants were distributed randomly into two groups, following the training terminology used in the review by MacInnis and Gibala (2017): (1) moderate-intensity continuous training (MICT, $n = 11$), which followed a high volume and moderate-intensity training programme; and (2) high-intensity interval training (HIIT, $n = 11$), which completed a low volume and high-intensity training programme with own body weight resistance exercises. The initial sample ($n = 22$) was reduced to a final sample of $n = 20$ due to the abandonment of two participants, one from each group. The woman from MICT group did not finish the training protocol because she suffered from an injury and the woman from HIIT abandoned because she became pregnant. After these abandonments, the final participation rate (adherence) was 91%, the same for each group. The descriptive characteristics for both groups are shown in Table 1. The participants were informed about and familiarised with all the experimental procedures, as well as their risks and benefits. They signed an informed consent form and were free to withdraw from the experimental protocol at any time.

Training programmes

Common schedule features

Figure 1 shows the common schedule features followed by all subjects involved in either MICT or HIIT training programmes. The complete schedule lasted for 12 weeks, in three non-consecutive sessions per week, from September to December, after 1-month rest in August. Following the classic nomenclature for periodisation designed by Matveyev (1981), the 12-week macrocycle training period was organised in 4 mesocycles that lasted for either 2 or 4 weeks. The two initial mesocycles (4 weeks each) corresponded to accumulation periods, the third mesocycle (2 weeks) was designed for transmutation and the last mesocycle (2 weeks) stood for realisation. Each mesocycle was further divided into 1-week microcycles, including: ordinary (low loads performed with sub-maximal intensities that increased with successive microcycles), shock (high load with a sudden increase in training volume or intensity), recovery (reduced training loads), pre-competitive (reduced loads and increased intensity, performed the week before the competition) and competitive (reduced loads and intensities, also called tapering, performed the week of the competition). At the end of the training programmes, all subjects participated in the same half-marathon race. During the training period, the following laboratory and field tests were carried out to adjust the training loads.

Maximal incremental tests in the laboratory All subjects performed two University of Montreal Track Tests (Léger and Boucher 1980) in the laboratory (L-UMTT) on a treadmill (Quasar h/p Cosmos® Sports & Medical GmbH, Nussdorf-Traunstein, Germany). The first test was performed

Table 1 Descriptive characteristics for the participants from high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) groups before and after each training programme, mean ± SD

	HIIT			MICT		
	Before	After	*P*	Before	After	*P*
Height (cm)	164.4 ± 5.5			168.6 ± 6.4		
Weight (kg)	60.7 ± 7.1	60.8 ± 6.7	0.866	64.0 ± 8.4	64.9 ± 8.6	0.328
BMI (kg·m^{-2})	22.5 ± 2.5	22.5 ± 2.4	0.897	22.6 ± 3.0	22.5 ± 3.1	0.347
Total body water (%)	54.5 ± 3.8	54.2 ± 3.6	0.570	51.9 ± 5.0	51.3 ± 5.3	0.301
Fat (% dry weight)	23.8 ± 5.3	24.0 ± 5.0	0.669	27.3 ± 6.8	28.2 ± 7.4	0.351
Muscle (% dry weight)	72.3 ± 5.1	72.1 ± 4.8	0.667	69.0 ± 6.5	68.2 ± 7.0	0.350
Bone (% dry weight)	3.9 ± 0.3	3.9 ± 0.3	0.301	3.7 ± 0.3	3.6 ± 0.4	0.308

BMI body mass index, *P* *p* values after running paired Student's *t* tests

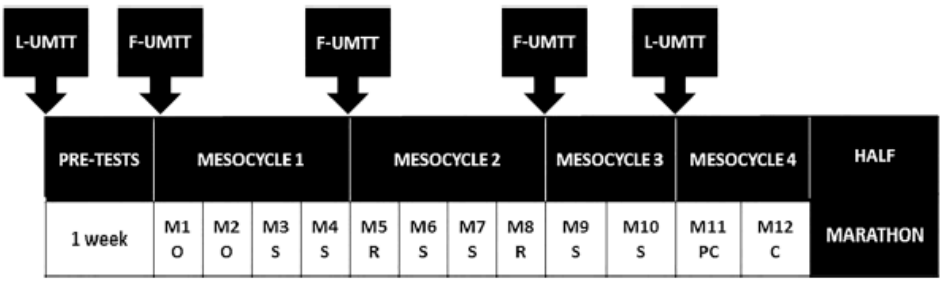

Fig. 1 Schedule followed by all the women participating in the two training programmes. Each microcycle (*M*) lasted for 1 week. The characteristics of each microcycle are indicated as: *O* ordinary (low loads performed with sub-maximal intensities, increasing with successive microcycles); *S* shock (high loads with a sudden increase in training volume or intensity); *R* recovery (reduced training loads); *PC* pre-competitive (reduced load and increased intensity, performed the week before the competition); *C* competitive (reduced loads and intensities, also called *tapering*, performed the week of the competition). *L-UMTT* laboratory UMTT, *F-UMTT*, Field UMTT

during the first week, prior to the beginning of the training programmes; and the second during the last week, prior to the half-marathon race (Fig. 1). Briefly, the L-UMTT consisted of: (1) an initial warm-up period of 4 min at a speed of 6 km/h and a slope of 0.6°; (2) an incremental phase with increases of 1 km/h every 2 min until exhaustion; (3) a recovery period of 6 min resting in a sit-down position. This test was preceded by a resting ECG (CardioScan v.4.0, DM Software, Stateline, Nevada, USA) and a 5-min standing rest to determine the VO_2 baseline with an automatic gas analysis system (TR-plus Metasys, Brainware SA, La Valette, France) equipped with a two-way mask (Hans Rudolph, Kansas, USA). The following parameters were measured: time to exhaustion (L-TE), heart rate (HR), oxygen uptake (VO_2), carbon dioxide output (VCO_2), oxygen pulse (O_2Pulse), respiratory minute volume (V_E), respiration rate (RR) and tidal volume (V_T). Participants were instructed to perform no strenuous exercise the day before the testing and to abstain from alcohol consumption in the 24 h prior to the tests. All tests were performed at the same time of day for all individuals. Ambient temperature during testing sessions was 22–25 °C with 45–55% relative humidity.

Maximal incremental tests in the field All subjects performed three field UMTTs (F-UTTM) on an official athletics track (Fig. 1). The first test was performed during the first week, prior to the beginning of the training programmes, and was separated by at least 72 h from the first L-UMTT to avoid the effects of residual fatigue on performance. The second F-UMTT was done after 4 weeks of training and the third test at the end of the 8th week. These tests were used to provide a follow-up of the training process and to adjust the training loads. The F-UMTTs were divided in the same phases as the L-UMTTs. With cones set at 50 m intervals along the track (inside the first line), the speed of each stage was controlled by an examiner equipped with a whistle and a chronometer, who emitted sounds when the subjects had to pass a cone, to maintain a constant speed for each test stage. The test finished when the participant was either behind a cone on three consecutive occasions or when she could no longer keep the pace required to pass the cones and decided to stop the exercise. Field time to exhaustion (F-TE) was recorded at the end of the test.

Additional data considered During the pre-test week and prior to the half-marathon race (Fig. 1), a complete body composition analysis was undertaken using Tanita BC-418 Segmental Body Composition Analyzer (Tanita Europe, Amsterdam, Netherlands). The participants were asked to record the duration of their menstrual cycle (days) and to monitor their basal body temperature (°C) during the menses days. Given the importance of sleep as an essential component of preparation for, and recovery from exercise training (Halson 2013), sleep quality was also surveyed using the Pittsburgh Sleep Quality Index (PSQI) questionnaire (Buysse et al. 1989). This is a self-rated questionnaire, which assesses sleep quality and disturbances over a 1-month time interval, that results from the sum of several scores (such as subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency and sleep disturbances) and yields a final score rated between 0 (very good sleep) and 21 (very bad sleep). Finally, all the women participating in the study took personal responsibility to register the following aspects of their training activities: (1) rating the perceived exertion (RPE) at the end of all exercising sessions and tests; (2) uploading data from HR monitors and GPS watches that measured training distances, durations and paces to a *personal diary* which was accessible to the researcher through the Strava app platform for Android or iOS (Strava, Inc.); (3) noting exercise activities in a *personal training diary* in paper format, facilitated at the beginning of the training programme and collected at the end of the study.

Moderate-intensity continuous training programme (MICT)

Table 2 shows the training programme followed by MICT group, which was based on Galloway and Galloway (2012). The programme consisted of three sessions per week distributed as follows:

- Two sessions of long run (LR) running (40 min and 60 min). To determine the training volumes, the average rhythm was calculated, yielding distances of 7 and 10 km for 40- and 60-min running times, respectively and rhythms of 5 min 45 s per km. Running speed for each subject was determined using the Magic Mile test (MM), consisting of multiplying the time needed to run a mile by a factor of 1.2. Moreover, the MM time was also used to calculate the correct pace for the half-marathon, multiplying by a factor of 1.2.
- A session of LR (increasing from 12 to 25 km) alternating with a session of interval run (IR) running consisting of 800-m intervals, with the number of repetitions and intensity increasing progressively every 2 weeks. Recovery from each repetition was always by walking.

During this programme, the total workout load increased gradually from approximately 23 km in the first week to approximately 43 km at the peak of the training. Since the training described on some occasions in the original protocol was based on running times, the kilometres run by the subjects of the MICT group are approximated. The total distance trained after the 12-week MICT programme was approximately 383 km and the overall time invested,

Table 2 Moderate-intensity continuous training (MICT) programme consisting of three sessions per week

Week	Session	Activity	Intervals	Intensity (%VO_2max)	Repetitions N (s)	Distance (trained)	Distance (WU-R)	Distance (total)
1	1	LR	60 min	70–75		≈ 10	1.5	≈ 33
	2	LR	40 min	70–90[a]		≈ 7	1.5	
	3	LR	12.0 km	70–75		12.0	1.0	
2	1	LR	60 min	70–75		≈ 10	1.5	≈ 27
	2	LR	40 min	70–90[a]		≈ 7	1.5	
	3	IR	0.8 km	95	6 (180)	4.8	2.0	
3	1	LR	60 min	70–75		≈ 10	1.5	≈ 36
	2	LR	40 min	70–90[a]		≈ 7	1.5	
	3	LR	14.5 km	70–75		14.5	1.0	
4	1	LR	60 min	70–75		≈ 10	1.5	≈ 29
	2	LR	40 min	70–90[a]		≈ 7	1.5	
	3	IR	0.8 km	95	8 (180)	6.4	2.0	
5	1	LR	40 min	70–75		6.0	1.5	≈ 35
	2	LR	40 min	70–75		≈ 7	1.5	
	3	LR	17.5 km	70–75		17.5	1.0	
6	1	LR	60 min	70–75		≈ 10	1.5	≈ 30
	2	LR	40 min	70–90[a]		≈ 7	1.5	
	3	IR	0.8 km	95	10 (180)	8.0	2.0	
7	1	LR	60 min	70–75		≈ 10	1.5	≈ 41
	2	LR	40 min	70–75		≈ 7	1.5	
	3	LR	20.0 km	70–75		20.0	1.0	
8	1	LR	60 min	70–75		≈ 10	1.5	≈ 32
	2	LR	40 min	70–75		≈ 7	1.5	
	3	IR	0.8 km	95	12 (180)	9.6	2.0	
9	1	LR	40 min	70–75		≈ 7	1.5	≈ 43
	2	LR	40 min	70–75		≈ 7	1.5	
	3	LR	25.0 km	70–75		25.0	1.0	
10	1	LR	40 min	70–75		≈ 7	1.5	≈ 30
	2	LR	40 min	70–90[a]		≈ 7	1.5	
	3	IR	0.8 km	95	14 (180)	11.2	2.0	
11	1	LR	60 min	70–75		≈ 10	1.5	≈ 28
	2	LR	40 min	70–75		≈ 7	1.5	
	3	LR	6.5 km	65–70		6.5	1.0	
12	1	LR	40 min	70		≈ 7	1.5	≈ 19
	2	LR	30 min	60–85		≈ 5	0.0	
	3	LR	30 min	60		≈ 5	0.0	

Distances expressed in km

≈ approximated distance, *IR* interval run, *LR* long run, *N(s)* number and resting times in seconds between repetitions, *WU-R* warm-up and recovery

[a]Running at magic mile speed (see text for details)

calculated as an average from all the participants, was 40 h and 30 min.

High-intensity interval training programme (HIIT)

Table 3 shows the training programme followed by HIIT group, designed with the objective of reducing training volume and time and increasing training intensity. The programme consisted of three sessions per week distributed as follows:

- An endurance session of long distance running (LR), increasing from 8 to 16 km. LR speed was calculated for each subject based on the percentage of VO_2max obtained after performing L-UMTT.

Table 3 High-intensity interval training (HIIT) programme consisting of three sessions per week

Week	Session	Activity	Distance (intervals)	Intensity (%VO_2max)	Intervals *N* (s)	Repetitions *N* (s)	Distance (Trained)	Distance (WU-R)	Distance (total)
1	1	IR	0.2	100	2 (180)	8 (30)	3.2	3.0	19.1
	2	WE					0.4	3.0	
	3	LR	8.0	80	1		8.0	1.5	
2	1	IR	0.4	90	2 (180)	4 (60)	3.2	3.0	24.3
	2	UH/FR	0.1/2.0	85/80	1	8/1	3.6	3.0	
	3	LR	10.0	80	1		10.0	1.5	
3	1	IR	0.2	100	2 (180)	10 (30)	4.0	3.0	21.9
	2	WE					0.4	3.0	
	3	LR	10.0	80	1		10.0	1.5	
4	1	IR	0.4	90	2 (180)	6 (60)	4.8	3.0	28.3
	2	UH/FR	0.1/2.0	85 / 80	1	10/1	4.0	3.0	
	3	LR	12.0	80	1		12.0	1.5	
5	1	IR	0.2	100	3 (180)	6 (30)	3.6	3.0	19.5
	2	WE					0.4	3.0	
	3	LR	8.0	80	1		8.0	1.5	
6	1	IR	0.4	90	3 (180)	4 (60)	4.8	3.0	30.7
	2	UH/FR	0.1/2.0	85 /80	1	12/1	4.4	3.0	
	3	LR	14.0	75	1		14.0	1.5	
7	1	IR	0.2	100	3 (180)	8 (30)	4.8	3.0	28.2
	2	WE	0	60	1		0.4	3.0	
	3	LR	16.0	75	1		16.0	1.0	
8	1	IR	0.4	90	3 (180)	4 (60)	4.8	3.0	30.7
	2	UH/FR	0.1/2.0	85 /80	1	12/1	4.4	3.0	
	3	LR	14.0	80	1		14.0	1.5	
9	1	IR	0.2	100	3 (180)	10 (30)	6.0	3.0	28.9
	2	WE					0.4	3.0	
	3	LR	15.0	75	1		15.0	1.5	
10	1	IR	0.4	90	1	10 (60)	4.0	3.0	27.9
	2	UH/FR	0.1/2.0	85 / 80	1	12/1	4.4	3.0	
	3	LR	8.0	80	1		12.0	1.5	
11	1	IR	0.2	100	1	10 (30)	2.0	3.0	23.5
	2	LR	5.0	70–85	1		6.0	3.0	
	3	LR	8.0	80	1		8.0	1.5	
12	1	LR	7.0	80	1		7.0	0.0	18.0
	2	LR	6.0	85	1		6.0	0.0	
	3	LR	5.0	60	1		5.0	0.0	

Distances expressed in km

FR fast run, *IR* interval run, *LR* long run, *N(s)* number and resting times in seconds between repetitions, *UH* uphill fast run and downhill easy run, *WE* own body weight resistance exercises, *WU-R* warm-up and recovery

- An interval running (IR) session, which alternated between 200 and 400 m, progressively increasing the number of repetitions and intensity. IR consisted of series of 200 m or 400 m grouped in 1, 2 or 3 blocks, with recoveries between series of the same block ranging from 30 s to 1 min and recoveries of 3 min between blocks.
- A session of uphill run and fast run (UH/FR) alternating with a session of own body weight resistance exercises (WE). UH consisted of climbing 100-m slopes of 10 to 12% at an intensity of 85% VO_2max, recovering by running downhill. When UH was finished, 10 min of FR (80% VO_2max) were performed. Own body weight resistance exercises (WE) used the women's body weight as load. After warm-up and stretch activities for 15 min, the protocol, based on Klika and Jordan (2013), had 12 stations with 1 exercise per station performed for 30 s with 10 s

between transitions. Exercises were: jumping jacks, wall sit, push-up, abdominal crunch, set-up onto chair, half squat, triceps dip on chair, plank, high knees/running in place, lunge, push-up and rotation and side plank. The total time for completing the circuit was 7 min, repeated 2 or 3 times depending on the training period. The exercises had to be performed at maximum intensity with the objective of increasing HR and global aerobic workload, since a large number of muscles were involved. When the circuit was finished, the women ran four sprints of 50 m to make the transition to racing on level ground. Finally, three sets of 30 s of Bosco's countermovement jump test (Bosco et al. 1983) were performed with the objective of improving the capacity to produce anaerobic power using the ATP-CP system and increasing the efficiency of using elastic energy to enhance muscle mechanical output.

During this programme, total workout load increased gradually from approximately 20 km in the first week to approximately 30 km at the peak of the training. The total distance trained after the 12-week HIIT programme was 301 km, 21% less than the total distance trained in the MICT programme. The overall time invested by the HIIT group, calculated as an average from all the participants, was 33 h and 26 min, representing 7 h and 4 min less than the time invested by MICT group, i.e., a 17% reduction in the time trained.

Statistical analyses

All data were statistically analysed using SigmaPlot 11 (Systat Software, Inc., San Jose, CA, 2008–2009). After checking normality (Kolmogorov–Smirnov test) and homoscedasticity (Levene test), data were analysed using unpaired (between groups comparisons: MICT vs HIIT) or paired Student's *t* tests (within groups comparisons: before vs after) and one-way ANOVA with repeated measures (within groups comparison at different training time points). Post hoc multiple comparisons after ANOVA testing were performed using the Holm-Sidak method. *P* values are given throughout the text, tables and figures, considering significant statistical differences at $P < 0.05$. The results are reported in the text and tables as mean ± SD, unless otherwise indicated. In the box and whisker plots, the box represents the interquartile range and shows the first and third quartiles separated by the median. The mean is represented by a black dot, and whisker end points represent the minimum and maximum values.

Results

Half-marathon

After the training period, all women participated in the same half-marathon and all completed the race successfully. For each group, Fig. 2 shows the comparison of the best previous finishing times obtained in the last 6 months before beginning the training (before) and the finishing times obtained in the half-marathon run after the 12-week training (after). Previous recordings were not statistically significant between groups ($P = 0.268$). Mean finishing times after both HIIT and MICT programmes were lower than previous ones, showing a reduction of 1 min 29 s in HIIT and 3 min 50 s in MICT. However, these improvements were not statistically significant (*P* values shown in Fig. 2). Although the group that followed HIIT programme had lower finishing times, the mean difference (4 min 16 s) was not statistically significant ($P = 0.331$).

Interval training power output and long run rhythm

After 12 weeks of training, the group of women that followed the HIIT programme showed a significant increase ($P < 0.001$) in power output for interval training, which was accomplished without increasing their RPE (Fig. 3a). The power output improvements accounted for 9% in 200 m series between before (223 ± 20 w) and after (244 ± 24 w),

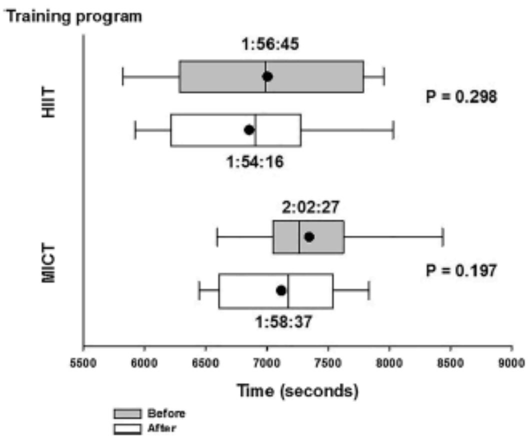

Fig. 2 Box plot showing the best previous finishing times (before) and the finishing times obtained in the half-marathon (after) for each training group (*HIIT* high-intensity interval training, *MICT* moderate-intensity interval training). Numbers above or below the black dots indicate the mean of the finishing times (hours:minutes:seconds). The *P* values after running *t* Student paired tests are also shown in the graphic

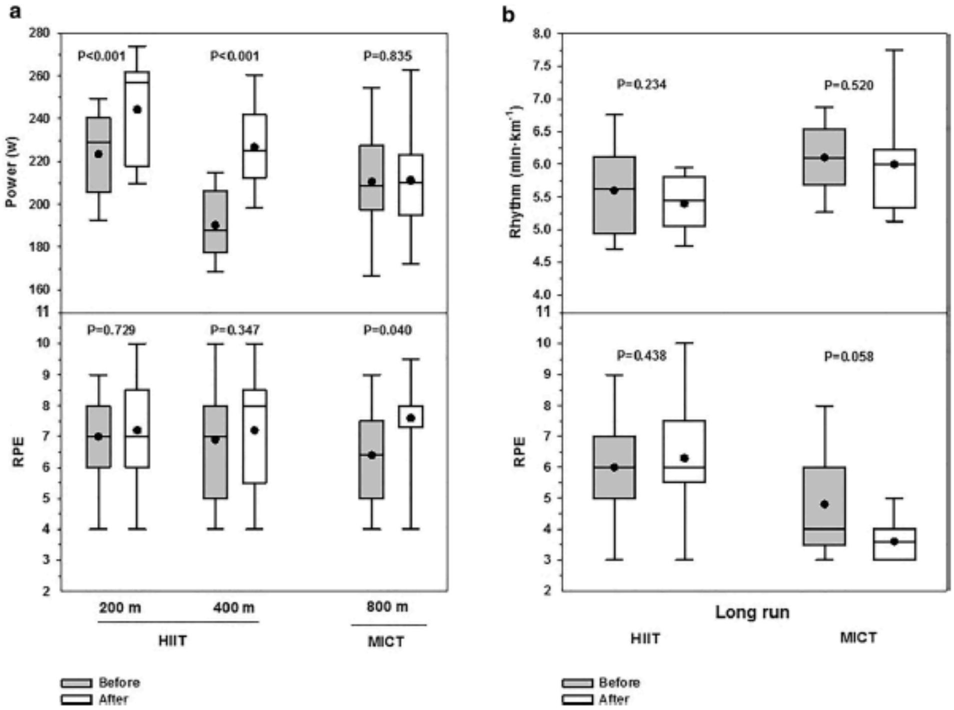

Fig. 3 Upper panels show the power output developed during interval training series (**a**) and the rhythm during the long run training (**b**) before and after the 12-week high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) programmes. Lower panels show the rating of perceived exertion (RPE) in each case. The *P* values after running *t* Student paired tests are shown in the graphic

and for 16% in the 400 m series (190 ± 16 w vs. 227 ± 19 w). In contrast, MICT group did not improve the power output in their interval training series (800 m), presenting the same values (211 w) in the first and the last weeks of training. However, a significant higher RPE score ($P = 0.040$) was evidenced in these women (Fig. 3a).

Regarding the long running sessions, the pacing rhythms ranged from 5 min 42 s to 6 min 10 s, showing no significant differences, either for HIIT or MICT groups, between before and after the training programmes (Fig. 3b). However, it is interesting to note that the RPE score registered in MICT group after the long run was lower ($P = 0.058$).

UMTT in the laboratory (L-UMTT)

An example of a complete laboratory test report is given as Supplemental Fig. 1 in pdf format to provide quality control insight on the data obtained after the UMTT performed in the laboratory.

Although the mean times to exhaustion (L-TE) after the training programmes increased by 2.9% in HIIT group and 4.4% in MICT group, these improvements were not statistically significant ($P = 0.302$ and $P = 0.098$, respectively). Figure 4 shows the measures of VO_2 relative to body weight, V_E and HR in the different phases of the two L-UMTTs (before and after the exercise programme). Supplemental Table 1 shows the data of the cardiorespiratory parameters (O_2Pulse, VCO_2, RR and V_T) for each minute during the recovery period of 6 min (R1-R6). Figure 4 and Supplemental Table 1 clearly indicate that both training programmes induced an improvement in the recovery from the maximal incremental test, since approaching to resting values in cardiorespiratory parameters were fastest after 12 weeks of training. This is evident in Fig. 4 where in all cases the *after* curve differentiates from the *before* curve from the 3rd minute of recovery after reaching the peak values. However, the greatest and most statistically significant differences in recovering from maximal exercise were observed in the runners that followed the HIIT training programme (see *P* values in Fig. 4 and Supplemental Table 1). Moreover, when the means of the percentage variation between *before*- and *after*-training values for

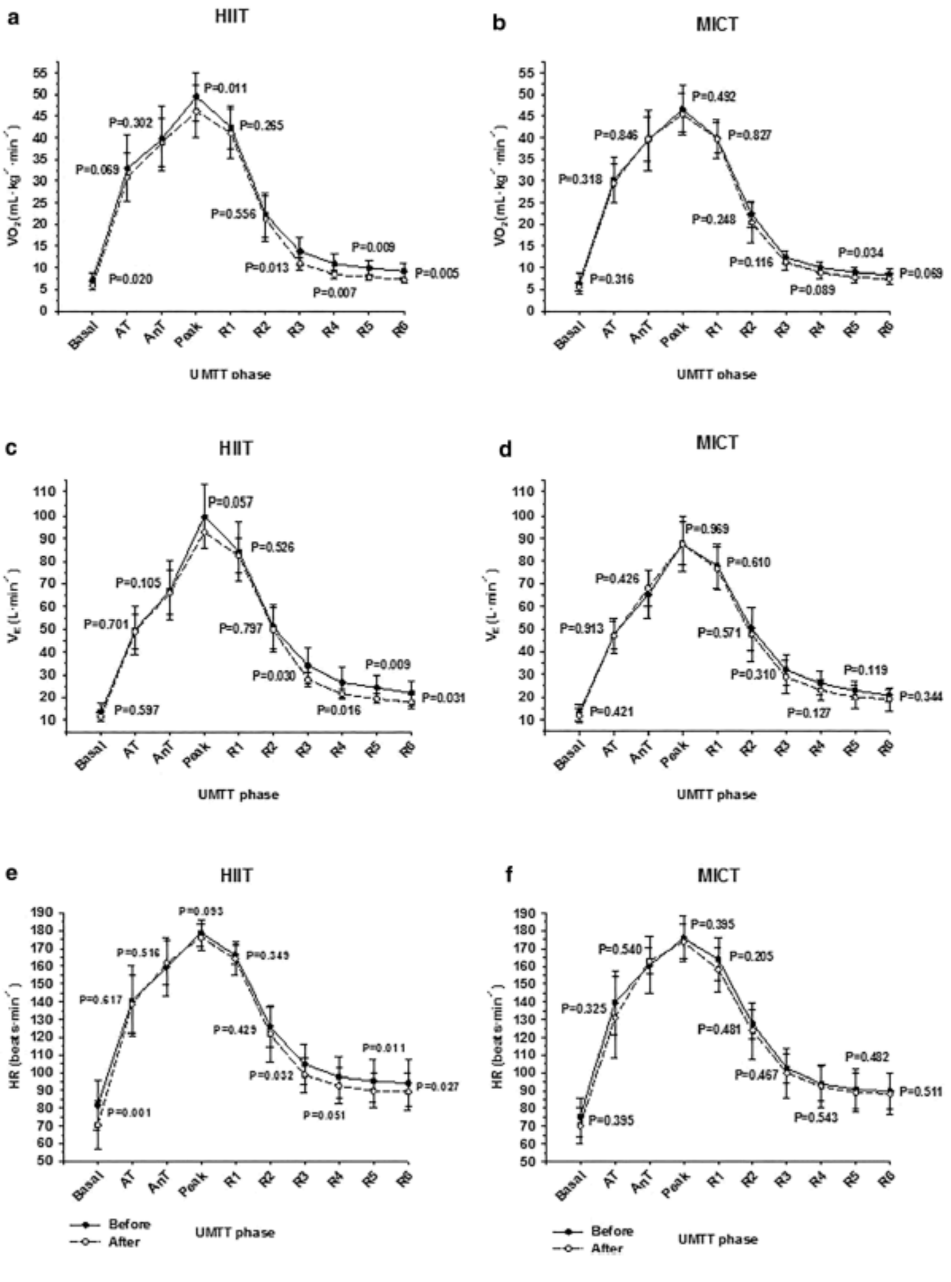

Fig. 4 Measurements of **a**, **b** oxygen uptake relative to body weight (VO_2), **c**, **d** Respiratory minute volume (V_E) and **e**, **f** heart rate (HR), in the different phases of two L-UMTTs: before and after high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) programmes. The *P* values after running *t* Student paired tests are shown in the graphic. Mean ± SD

R3–R6 were calculated from values in Fig. 4, the HIIT group presented variations of 21% (VO_2), 19% (V_E) and 6% (HR), which contrasted with the variations of 11% (VO_2 and V_E) and 2% (HR) obtained in the MICT group. Values for the parameters shown in Supplemental Table 1 also exhibit this trend, with mean percentage variations

(HIIT vs MICT) of 18% vs 10% (O_2Pulse), 22% vs 13% (VCO_2) and 11% vs 3% (RR). It is also of interest to note that the resting HR of women that followed the HIIT programme significantly decreased ($P < 0.001$, Fig. 5e) after the 12-week training, whilst the decrease was not significant in MICT runners ($P = 0.395$, Fig. 5f).

Regarding peak values, it is noteworthy that VO_2 and V_E were significantly reduced after the HIIT programme (Fig. 4a, c), which contrasted with MICT group, where no significant differences at peak values were recorded (Fig. 4b, d).

UMTT in the field (F-UMTT)

Figure 5 shows the individual and mean field times to exhaustion (F-TE) after performing three F-UMTTs: before beginning (T1), after 4 weeks (T2) and after 8 weeks (T3) of training. Irrespective of the programme followed, all runners significantly improved their F-TE after 4 weeks and, with some exceptions, also after 8 weeks.

Menstrual health and sleep quality

No significant differences were recorded between groups in the duration (days) of the menstrual cycle (HIIT: 5.2 ± 1.4; MICT: 4.6 ± 1.1; $P = 0.430$) nor in the basal temperature (°C) during the menses days (HIIT: 36.1 ± 0.46; MICT: 36.1 ± 0.37; $P = 0.853$). Sleep quality was similar in both groups (HIIT: 5.5 ± 1.6; MICT: 5.1 ± 1.1; $P = 0.646$), with mean PSQI scores distributed in the first quartile of the scale (good sleepers).

Discussion

A HIIT programme for middle-aged women, training for a half-marathon at the recreational level, achieved similar performance results in terms of finishing times after the race as those obtained after the MICT programme. This alternative HIIT elicited a significant increase in power output for their interval training series without increasing the RPE, which contrasted with MICT group who did not improve the

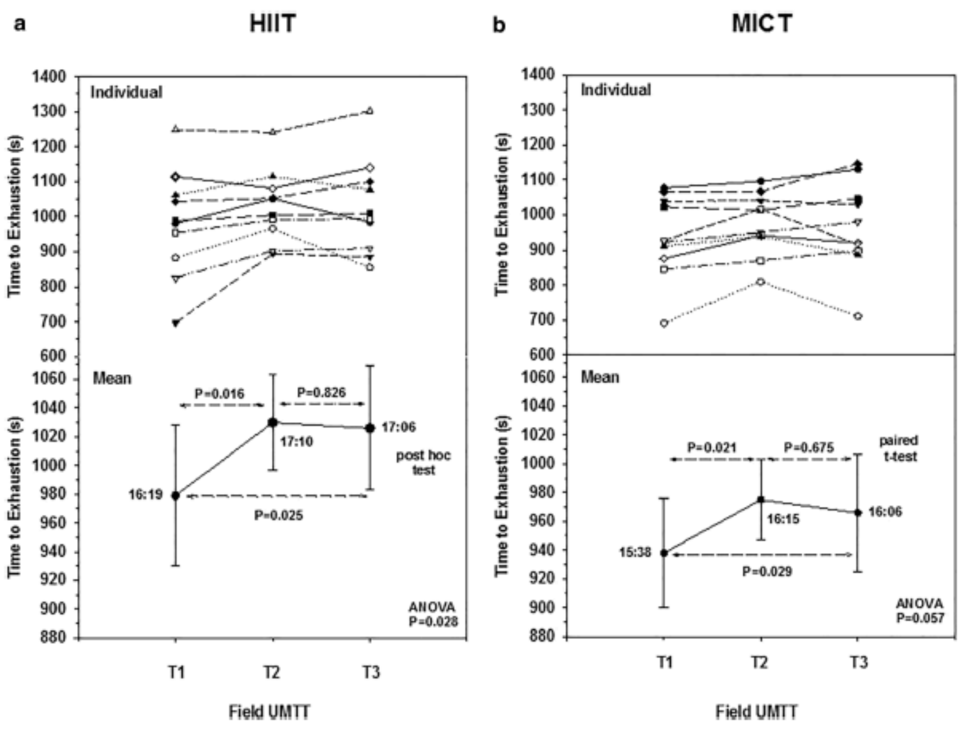

Fig. 5 Time to exhaustion after performing three field UMTTs before (T1), after 4 weeks (T2) and 8 weeks (T3) of high-intensity interval training (HIIT) (**a**) and moderate-intensity continuous training (MICT) (**b**). Upper panels show values for each single subject and lower panels are the mean ± SEM for each group. *P* values after running a one-way repeated measures ANOVA are given in the lower panels with *P* values after running the post hoc multiple comparison test by Holm–Sidak procedure

power output in their interval training series and increased their RPE score. Moreover, women that followed HIIT programme recovered key cardiorespiratory functional parameters faster from maximal exercise than those that followed the MICT programme. All these findings suggest that a HIIT triggered physiological adaptations aimed to improve aerobic and anaerobic power, which allowed similar performance results as MICT but involving a 21% less training volume and a 17% less training time.

Half-marathon finishing times

As shown in Fig. 2, both training methods were effective to enable subjects to successfully finish the half-marathon after 12 weeks of training. Although not statistically significant, there was a mean quantitative improvement in the half-marathon times, ranging from 2% (HIIT) to 3% (MICT), despite ours being a group with a medium level of training before starting the study. We value the improvements positively in both groups, especially in the HIIT group because they obtained similar finishing times after training fewer kilometres (21% less distance) and decreasing in 17% the amount of time invested in training. Considering the average finishing times, the women that followed the HIIT programme reduced their records in 2 min and 28 s. To assess the relevance of this result, we have considered the positions remaining between this time lapse in the three last editions (2018/2019/2020) of the Barcelona half-marathon for the category W40 (women aged 40–49 years). The improvement in the final position after reducing the finishing time from 1:56:45 to 1:54:16 (min:sec) would have been a rise of 73/90/82 places from a total of participants in W40 category of 1149/1454/1647, respectively (Barcelona City Hall 2020). We consider that, for a recreational runner, this improvement in the final position it would be rewarding. Moreover, given that the endurance training in MICT group was more akin to the running conditions of a half-marathon, it is interesting to note that the HIIT training schedule enabled this group to complete the race with no significant difference in performance compared to MICT group.

Over the last decade, several studies involving HIIT in sprint sports disciplines have demonstrated improvements or, at least, similar results in performance after the HIIT intervention programme. For example, Hazell et al. (2010) registered 3–5% improvements in a 5 km time trial on a cycle ergometer after 2-week HIIT cycle training schedules. Kilen et al. (2014) found that swimmers, after a 12-week programme of HIIT, which reduced their training volume by 50%, achieved similar performances in 100-m and 200-m freestyle tests. More recently, improvements after HIIT interventions have been reported in 2000 m rowing time trials (Ní Chéilleachair et al. 2017) and in swimming and running times in a sprint-distance triathlon (García-Pinillos et al. 2017). Moreover, when longer aerobic performances were considered, such as those involving from 20- to 60-min cycling trials, HIIT interventions achieved time improvement of between 4 and 10% (Burgomaster et al. 2006; Gibala et al. 2006). Regarding preparation for endurance running races, Silva et al. (2017) found a 2.3% non-significant reduction in 5 km time trials after a 4-week HIIT. Hottenrott et al. (2012) compared high intensity with continuous training for a half-marathon race preparation. Although the schedules for high-intensity and continuous trainings were quite different from those used in our study, the period of training (12 weeks) and the age and condition of the participants (recreational runners of 42 years old) were equivalent. They reported no significant differences in the half-marathon finishing times between the training programmes, which are also reflected in our results. Thus, although with remarkable differences in training schedules, both studies allow us to conclude that a HIIT programme, even with conditions that are very different to those of a half-marathon, enabled runners to complete the race without differences in performance. Since we have not measured muscle metabolic markers, we can only speculate on the mechanisms responsible for the absence of differences in performance between the training programmes. As has already been reported, some HIIT protocols elicit comparable responses in muscle metabolism to those induced by endurance training. Among these are the comparable increases in mitochondrial potential, measured by the activity of oxidative enzymes (cytochrome c oxidase or citrate synthase) in muscle glycogen stores or muscle buffering capacity (Burgomaster et al. 2005; Gibala et al. 2006).

Series power output and long run rhythm

The power output developed during interval training series significantly improved after HIIT training, which happened without the runners having higher fatigue perception, as is deduced from their RPE ratings (Fig. 3a). In contrast, power output did not increase after training in the MICT group, who, in addition, presented higher fatigue perception ratings. These findings indicate than our protocol of interval intensity training improved the anaerobic performance, which was not achieved after a classic MICT training based on endurance exercises. On the other hand, if we compare the results obtained in long run training sessions (Fig. 3b), both groups improved their running pace. Interestingly, there was an almost significant decrease in RPE ($P=0.058$) in the MICT group, indicating that those who performed a protocol relying on endurance exercises had a lower fatigue perception after long run tests. All these data match the conclusions derived from the studies of Burgomaster et al., applying different training HIIT protocols, who found that HIIT induced metabolic adaptations in the skeletal muscle comparable to traditional endurance exercise (Burgomaster et al. 2006, 2008).

Physiological parameters

Figure 4 and Supplemental Table 1 clearly show that the women who followed the HIIT training programme recovered faster after the treadmill VO_2max test than those who trained with the MICT schedule. Several cardiorespiratory parameters such as HR, V_T and V_E presented significant reductions from the third minute of recovery after reaching peak VO_2, which resulted in a significant decrease in oxygen consumption from this temporal point to the end of the test (minute 6). This indicates that the HIIT training programme elicited different adaptive changes from those induced by conventional MICT programmes. The high intensity performed during the series of high power output and resistance sessions in HIIT programme could promote physical and biomechanical changes that allow modifying the efficiency at high workloads (close to the maximum reached during the L-UMTT). This is evidenced by the significant statistical increases observed in the 200 m and 400 m series (Fig. 3a), and the maximum peak of oxygen consumption at the maximal workload achieved (Fig. 4). At the same time, HIIT training program can promote changes in oxygen uptake and transport, as might indicate the data obtained during recovery in the L-UMTT in ventilatory the parameters such as V_E (Fig. 4), O_2 pulse, RR and V_T (Supplemental Table 1). We speculate that the combination of both intensity and intermittency derived from the HIIT training triggered several physiological mechanisms that improved endurance capacity. Thus, an increase of the transport oxygen capacity or a more efficient oxygen extraction at the muscular level could explain the differences reported here. In fact, some of these mechanisms have already been proposed and include improvements in skeletal muscle mitochondrial potential (Burgomaster et al. 2005; Daussin et al. 2008) or increases in skeletal muscle blood flow and vascular conductance (Krustrup et al. 2004). Moreover, in addition to these differences obtained during the recovery phase, a significant reduction in resting HR was observed after HIIT training while the resting HR after MICT training was not altered (Fig. 4e, f). As the resting HR drops, the reserve HR increases, meaning that HIIT trained runners will have their endurance performance capacity improved.

Surprisingly, in contrast to other previous studies (Helgerud et al. 2007; MacPherson et al. 2011), after the HIIT programme, we obtained significantly lower peak VO_2 and V_E values. However, in the tests performed in our laboratory, women following HIIT and MICT programmes developed similar loads. Thus, a reduction in peak respiratory values may indicate an increase in efficiency from the ventilatory point of view, leading to beneficial effects for the HIIT group because of a reduction in the energy cost of running (Silva et al. 2017) and running economically at high speeds.

Practical applications

This study validates an alternative training protocol that incorporates high-intensity interval training. The protocol improved aerobic and anaerobic performance and obtained similar or better results than a high-volume training schedule. The reduction in training volumes will help practitioners to improve their training adherence by avoiding the "lack of time" disincentive. Moreover, the study provides additional interesting insights, having been carried out among amateur women runners, aged 35–45 years; a little studied demographic that typically experiences serious difficulties reconciling daily professional and family life with sports practice. Thus, an amateur training protocol that reduces training volume in favour of intensity without affecting the final performance results could be a valuable and attractive training alternative.

Strengths, limitations and future perspectives

In our opinion, the strongest point of the work is the sample used: middle-aged experienced recreational female runners. This demographic group has recently experimented one of the greatest increases in half-marathon participation (Knechtle et al. 2016; Running USA 2017) and often must cope with spare time shortages for training derived from familiar and work responsibilities (Tanaka and Seals 2008). The previous experience that these women runners had and the homogeneity of the sample facilitated the application of the training programs and the analysis of the results. Paradoxically, the characteristics of the sample are, at the same time, a limitation. Probably, using men or women of a different age could have offered different responses to the same training protocol, at least in the magnitude of the changes. The training experience of the participants would also have influenced the response to training, since it is well known that the starting point of functional capacity and individual sports experience influences the response to regular physical activity (Bouchard and Rankinen 2001). Other source of limitations is the duration of the program, limited to 3 months to reduce the risk of abandonment, which could have produced different results if it would have been longer. In future research, each of these limitations should be assessed with the aim of optimizing the type of training and its duration according to the characteristics of each runner. Further studies could also contemplate quantifying the physiological stress caused by the different training programmes by measuring salivary or circulating stress hormones (such as cortisol or testosterone), and circulating levels of inflammatory, oxidative stress and muscle damage markers in different temporal points of training and after the half-marathon running. Finally, qualitative data of enjoyment during the training sessions could complement data on RPE and sleep quality.

Conclusions

Recreational female middle-aged runners following 12 weeks of HIIT for a half-marathon run improved their previous finishing times in a similar way than did a balanced group of women training a MICT programme. The HIIT programme improved anaerobic performance and aerobic recovery from maximal tests involving a 21% less training volume and a 17% less training time than the MICT programme. Thus, the findings of the present study indicate that a training protocol based on intensity with reduced running volumes and time may provide an alternative exercise model for the improvement of half-marathon results in female recreational master runners.

Author contributions CF and JRT conceived and designed research. JBB and CF conducted experiments. JBB, CF and JRT analysed data. JBB and JRT wrote the draft manuscript. JM, GV and TP corrected the draft manuscript and contributed analytical tools. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Ethical Committee of the University of Barcelona (Institutional Review Board number IRB00003099), in accordance with current Spanish legislation and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Artículo III

Bonet JB, Magalhães J, Viscor G, Pagès T, Ventura JL, Torrella JR, Javierre C (2020) Inter-individual different responses to continuous and interval training in recreational middle-aged women runners. *Frontiers in Physiology* 11:579835.

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Inter-Individual Different Responses to Continuous and Interval Training in Recreational Middle-Aged Women Runners

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A crucial subject in sports is identifying the inter-individual variation in response to training, which would allow creating individualized pre-training schedules, improving runner's performance. We aimed to analyze heterogeneity in individual responses to two half-marathon training programs differing in running volume and intensity in middle-aged recreational women. 20 women (40 ± 7 years, 61 ± 7 kg, 167 ± 6 cm, and VO_2max = 48 ± 6 $mL·kg^{-1}·min^{-1}$) underwent either moderate-intensity continuous (MICT) or high-intensity interval (HIIT) 12-week training. They were evaluated *before* and *after* training with maximal incremental tests in the laboratory (VO_2max) and in the field (time to exhaustion, TTE; short interval series and long run). All the women participated in the same half-marathon and their finishing times were compared with their previous times. Although the improvements in the mean finishing times were not significant, MICT elicited a greater reduction (3 min 50 s, P = 0.298), with more women (70%) improving on their previous times, than HIIT (reduction of 2 min 34 s, P = 0.197, 50% responders). Laboratory tests showed more differences in the HIIT group (P = 0.008), while both groups presented homogeneous significant ($P < 0.05$) increases in TTE. Both in the short interval series and in the long run, HIIT induced better individual improvements, with a greater percentage of responders compared to MICT (100% vs 50% in the short series and 78% vs 38% in the long run). In conclusion, variability in inter-individual responses was observed after both MICT and HIIT, with some participants showing improvements (*responders*) while others did not (*non-responders*) in different performance parameters, reinforcing the idea that individualized training prescription is needed to optimize performance.

Keywords: middle-aged women, half-marathon runners, high intensity interval training, exercise and sport, moderate intense endurance exercise training, non-responder, responder

INTRODUCTION

One of the general bases of sports training is the principle of individuality, grounded in the specific adaptive responses shown by individuals to a given training program (Matveyev, 1981). This principle of individuality means that the selection or combination of different performance indicators must be carefully chosen to properly assess the training process, since there could be different responses to the same training program (Kenney et al., 2012). A pioneering study by Prud'homme et al. (1984) found considerable individual differences in the adaptive capacity to training in ten pairs of monozygotic twins participating in a short-term endurance training program, with sensitivity to maximal aerobic power being largely genotype-dependent. Later, although similar adaptations in performance and physiological parameters were reported after training schedules involving different exercise volumes and intensities (Gibala et al., 2006; Burgomaster et al., 2008; Scribbans et al., 2014), several studies demonstrated the existence of inter-individual variability in training responses, both after moderate-intensity continuous training (MICT) and high intensity interval training (HIIT; Astorino and Schubert, 2014; Gurd et al., 2016; Whipple et al., 2018).

Participation in half-marathon races has increased across years, especially for the middle-aged female runners (Knechtle et al., 2014, 2016; Knechtle and Nikolaidis, 2018). For example, data from races held in Switzerland between 1999 and 2014 indicate that more endurance athletes compete in half-marathon than in marathons, and that the finisher's men-to-women ratio decreased significantly throughout the years, meaning an increase in women's participation (Knechtle et al., 2016). It is also interesting to note that, between 2014 and 2016 in the world's largest half-marathon (GöteborgsVarvet), approximately 44% of the women's runners were in the middle-aged group (35 to 50 years; Knechtle and Nikolaidis, 2018). Although amateur running is a leisure activity that has become increasingly popular in recent decades (van Dyck et al., 2017), there are still a few studies focusing on middle-aged non-elite women recreational runners (Machado et al., 2011). Only recently, some studies have been centered on middle-aged female marathon recreational runners, highlighting the effect of sex and age on pacing (Nikolaidis et al., 2018), and reporting new data on anaerobic power and neuromuscular fitness for this population group (Nikolaidis and Knechtle, 2018). These findings are of practical relevance for practitioners and coaches, considering their implications in racing times. Thus, to determine the variability (inter-individual differences) in the responses to different training programs among middle-aged women who normally participate in recreational running would be useful for optimizing strength and pacing times and hence improving health-related physical fitness and race finishing times.

During the last decade, several schedules for preparing half-marathon have been published including different strategies regarding the volume and the intensity of the training. There are programs prioritizing MICT with maximal weekly running volumes of 40 km and long run sessions of 25 km (Galloway and Galloway, 2012), contrasting to those where HIIT and fast pace short distance runs predominate (Lanier et al., 2012). Other schedules alternate high-volume programs with speed and hill training (Hamilton and Sorace, 2018) or with resistance training (Hagerman, 2005). A recently published study from our laboratory (Bonet et al., 2020) was aimed to assess if a mixed program, with HIIT sessions of 40 s to 90 s followed by short recovery periods and interspersed with low-volume endurance sessions, was better for training a half-marathon than a traditional MICT program, based on high-volume endurance sessions of moderate-intensity training. We reported a detailed description of the training schedules, data on the performance and physiological changes elicited by each training program.

Here, we present a preliminary brief research report focused on the analysis of the heterogeneity in individual responses to the training programs. We analyze some parameters that could affect performance and could induce different responses depending on the training program. Our hypothesis was that the HIIT program would result in a more homogeneous response than the MICT program, since HIIT would activate more skeletal muscle metabolic ways and promote greater changes in cardiovascular structure and function. To study the inter-individual variation in response to training is of interest because it has been reported that individuals who fail to respond to an endurance exercise protocol may respond to other training protocols, such as resistance or interval training (Hautala et al., 2006; Bonafiglia et al., 2016). Identifying responders and non-responders to a given training protocol would allow creating individualized pre-training schedules and improve runner's performance. This would be especially interesting in the population group studied here: middle-aged women, who run at a recreational level, normally having difficulties in combining sports practice with daily professional and family life (Macias et al., 2014). As suggested in a recent review (Pickering and Kiely, 2019), more research is needed to identify responders and non-responders to exercise interventions so that alternative training schedules can be developed for non-responders to increase their fitness in an effective manner.

MATERIALS AND METHODS

Subjects

A total of 20 women aged 40 ± 7 years, 61 ± 7 kg, and 167 ± 6 cm with a body mass index of 23 ± 3 (mean $\pm$ SD) participated in this study. They were recruited from different running clubs in the city of Barcelona (Spain) after completing a questionnaire and an interview to assess the following inclusion criteria: to be pre-menopausal, non-smokers, to have no injuries and not to take any medication (including oral contraceptives). Moreover, they age range must be between 35 and 45 years and be regular runners, training a minimum of 5 h and 3 days per week and with previous experience in running half-marathons recreationally. The women were randomly divided into two training groups ($n = 10$ in each): (1) MICT group, which participated in a high-volume and low-intensity training program; and (2) HIIT group, which completed a low-volume and high-intensity interval running program with bodyweight resistance exercises. No significant statistical differences were observed between randomly selected groups in performance parameters prior to training (**Table 1**). There were no significant differences in the anthropometrical parameters between the groups both at the beginning and at the end of the training protocols. After being informed about the experimental procedures, as well as their risks and benefits, the participants signed an informed consent form and were free to withdraw from the experimental protocol at any time. The study was developed in accordance with the Declaration of Helsinki concerning the ethical principles of human experimentation and was approved by the Institutional Ethics Committee of the University of Barcelona (Institutional Review Board number, IRB00003099).

Training Programs

Both training programs lasted for 12 weeks, involving 3 non-consecutive sessions per week, from September to December after a 1-month rest in August. For a detailed explanation of the training programs, see Bonet et al. (2020). After the training programs, all the women participated in the same half-marathon race held in Vilanova i la Geltrú (Spain), located at sea level on the Mediterranean coast (41°13'27" N, 1°43'33" E). The race had a mostly flat profile with slight ups and downs between kilometer 9th and 10th and from the 20th to the finish line. Weather conditions during the race were sunny and windless with a temperature of 15°C.

Moderate-Intensity Continuous Training

The MICT group followed a training program based on the one described in Galloway and Galloway (2012). This consisted of 2 days of continuous running (40 min and 60 min) and 1 day alternating between long-distance running (from 12 km to 25 km) and 800-meter intervals every week, that were run in approximately 4 min. The total distance trained was approximately 383 km and the overall time invested, calculated as an average among all the participants, was 40 h and 30 min.

High-Intensity Interval Training

The HIIT group participated in a weekly training program that was designed to reduce training volume and increase training intensity. The program consisted of a first session of long-distance running (from 8 km to 16 km), a second day dedicated to interval running (200-m and 400-m series), and a third day that alternated between an uphill run and a fast run with bodyweight resistance exercises. The speed of the long-distance running on the first day was calculated for each subject based on their percentage of VO_2max. The 200-m or 400-m series on the second day were grouped into 1, 2, or 3 blocks, with recoveries between series of the same block ranging from 30 s to 1 min and the recoveries between blocks lasting 3 min. The uphill run on the third day of the week consisted of climbing 100-m 10% to 12% slopes at an intensity of 85% VO_2max, which was followed by running downhill at a slow pace and then a 10-min fast run at 80% VO_2max. This was combined with a circuit of 12 stations of weight resistance exercises performed at maximum intensity, based on the training described in Klika and Jordan (2013). When the circuit was completed, 4 50-m sprints and 3 30-s sets of Bosco's countermovement jump tests (Bosco et al., 1983) were performed in order to improve anaerobic power and increase the efficiency of using elastic energy. The total distance trained by the HIIT group was approximately 301 km and the overall time invested, calculated as an average among all the participants, was 33 h and 26 min. Thus, the women in the HIIT program covered 21% less distance and invested 17% less time than those in the MICT group.

TABLE 1 | Finishing times for the half-marathon and results from the maximal incremental tests performed in the laboratory (VO_2max) and on the athletic track (field time to exhaustion, TTE) *before* and *after* the training programs.

	Whole group			MICT			HIIT			
Finishing time (h:min:s)	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	***P*-value MICT vs HIIT**
Before	1:59:36	0:45:33	9.4	2:02:27	0:32:51	7.1	1:56:45	0:36:23	11.3	0.268
After	1:56:26	0:36:54	8.4	1:58:37	0:23:40	7.0	1:54:16	0:36:54	9.6	
P-value	0.085			0.298			0.197			
VO_2max (mL·kg^{-1}·min^{-1})	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	***P*-value MICT vs HIIT**
Before	47.9	18.3	11.6	46.1	14.6	10.5	49.7	16.2	11.9	0.153
After	46.0	18.7	11.3	45.8	13.7	9.8	46.1	18.7	13.2	
P-value	0.05			0.833			0.008			
TTE (h:min:s)	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	***P*-value MICT vs HIIT**
Before	0:15:59	0:09:17	14.2	0:16:19	0:06:26	12.7	0:15:38	0:09:11	15.8	0.508
After	0:16:36	0:09:52	13.3	0:17:06	0:07:16	13.4	0:16:06	0:07:27	13.1	
P-value	0.002			0.035			0.029			

Results are shown for the whole group consisting of all the women participating in the study, as well as separately for the moderate-intensity continuous training (MICT) and high-intensity interval training (HIIT) groups. Data are given as the mean, range and coefficient of variation (CV). P-values in the rows show the statistical significance of the differences between before and after conditions, as determined using paired Student's t-test. P-values in the last column show the absence of statistical significance between randomly assigned participants to MICT and HIIT programs prior to the training.

Maximal Incremental Tests

Laboratory

All subjects performed two University of Montreal Track Tests (Léger and Boucher, 1980) in the laboratory (L-UMTT) on a treadmill (Quasar h/p Cosmos® Sports & Medical GmbH, Nussdorf-Traunstein, Germany) to determine the maximal oxygen uptake (VO_2max). The first test was performed during the first week, prior to the beginning of the training programs; and the second during the last week, prior to the half-marathon race. Briefly, the L-UMTT consisted of: (1) an initial 4-min warm-up period at a speed of 6 $km{\cdot}h^{-1}$ and a slope of 0.6°; (2) an incremental phase with increases of 1 $km{\cdot}h^{-1}$ every 2 min until exhaustion; and (3) a 6-min recovery period that involved sitting down to rest. This test was preceded by a resting electrocardiogram (ECG; CardioScan v. 4.0, DM Software, Stateline, NV, United States) and a 5-min standing rest to determine the baseline VO_2 with an automated gas analysis system (TR-plus Metasys, Brainware SA, La Valette, France) equipped with a two-way mask (Hans Rudolph, Kansas, United States).

Field

To provide a follow-up to the training process and adjust the training loads, two field UMTTs (F-UTTM) were conducted on an official athletics track. Field time to exhaustion (TTE) was recorded at the end of each test. The first test was performed prior to the beginning of the training programs, separated by at least 72 h from the first L-UMTT to avoid the effects of residual fatigue on performance. The second F-UMTT was conducted at the end of the 8th week of training. Cones were set at 50-m intervals along the track and the speed of each stage was controlled by an examiner equipped with a whistle and a chronometer, who emitted sounds when the subjects had to pass a cone in order to maintain a constant speed for each stage of the test. The test finished when the participant was either behind a cone on three consecutive occasions or when she could no longer keep the pace required to pass the cones and decided to stop the exercise.

Two field tests, at the beginning and at the end of the training periods, were performed to assess power performance in short-run series (200 m and 400 m for HIIT and 800 m for MICT) and the long run pace (8 km for both training programs). The first short-run series test (*before*) was performed during the first week (200-m and 800-m series) and second week (400-m series) of training, whereas the second test (*after*) was conducted during the tenth (200-m and 800-m) and eleventh (400-m series) week. The long run tests were performed for both training programs during the first (*before*) and tenth (*after*) week of training.

Statistical Analysis

We powered the sample size on the variable finishing time to fit the power parameters of $\alpha = 0.05$ and $\beta = 0.20$, estimating both the size of the change to be detected and the size of the standard deviation change as 0.05. A minimum sample size of $n = 10$ was required for paired t-tests (comparing *before* vs *after* parameters for each training program). Since an initial sample of twenty-two participants was selected during the recruitment procedure, the study began with eleven participants in each group. However, one woman from each group failed to follow the complete training schedule. Thus, the final sample contained 10 women per group. After checking normality (Kolmogorov-Smirnov test) and homoscedasticity (Levene test), to evaluate changes in the performance indicators, we used paired Student's t-tests (comparisons: *before* vs *after*). One-way ANOVA was run to evaluate intragroup differences in the finishing times between the different types of responders. P-values are given throughout the text, tables and figures, considering significant statistical differences at $P < 0.05$. To evaluate variability in the responses to the training programs, we used the coefficient of variation (CV), i.e., the ratio between the standard deviation and the mean (expressed as %). This parameter is normally used to assess variability in a group's response to a stimulus such as a training program. All data were statistically analyzed using SigmaPlot 11 (Systat Software, Inc., San Jose, CA, United States, 2008–2009).

RESULTS

Half-Marathon Finishing Times

After completing the training period, the mean finishing time obtained in the half-marathon by the whole group (i.e., irrespective of the training schedule) showed a non-significant ($P = 0.085$) improvement (**Table 1**). The previous finishing times were obtained in the half-marathon held 10 months before in Granollers (Spain, 41°36'30" N, 2°17'20" E), with a similar profile, 145 m of elevation and similar weather conditions. This improvement consisted of a 2.4% reduction compared to the mean of previous finishing times, indicating a decrease of 3 min and 10 s compared to the mean of previous finishing times. However, when the data were analyzed by considering the training programs separately, the MICT and HIIT groups behaved differently.

The MICT group showed a non-significant ($P = 0.298$) 2.9% reduction compared to its mean of previous finishing times (**Table 1**), indicating that it took them 3 min 50 s less to complete the half-marathon compared to previous times. The times before and after the training program showed a similar intragroup variability (CV∼7%), with more than a 9-min difference in the range of the times obtained in the half-marathon after the training protocol. Among the women that followed this training program, three did not improve on their previous finishing times, while another three achieved a time reduction greater than 10% (**Figure 1A**). Thus, regarding their response to the MICT program, the participants were classified into three categories showing significant differences ($F = 159.9$, $P < 0.001$) in their mean finishing times: (i) three subjects were ***high responders***, with a mean time reduction of 15 min; (ii) four subjects could be considered *normal responders*, achieving a mean decrease in their finishing time of 2 min 26 s; and (iii) three subjects were *non-responders*, increasing on their mean previous finishing time by 5 min 31 s.

The HIIT group showed a non-significant ($P = 0.197$) 1.8% decrease compared to its mean of previous finishing times (**Table 1**), which meant that it took them 2 min 34 s less to complete the half-marathon compared to their previous finishing

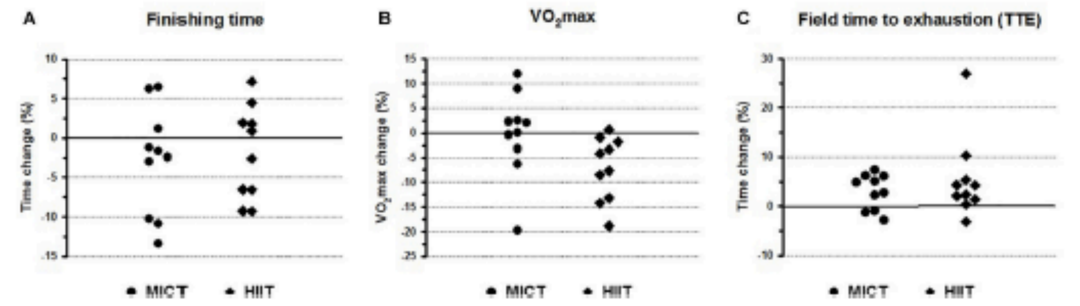

FIGURE 1 | Individual percentage changes *before* and *after* the training program in women participating in moderate-intensity continuous training (MICT) and high-intensity interval training (HIIT). **(A)** percentage changes in time comparing previous (*before*) finishing times and the finishing times registered in the half-marathon race after the training programs. **(B)** percentage changes in VO_2max obtained in a laboratory maximal incremental test *before* and *after* the training programs. **(C)** percentage changes in time to exhaustion (TTE) obtained in a field maximal incremental test *before* and *after* the training programs.

times. The times obtained *after* the training program showed a slight reduction in intragroup variability (CV = 9.6%) compared to the times obtained *before* the training (CV = 11.3%), but with a similar range difference of ~36 min in both cases. The women in the HIIT group were classified into two categories (**Figure 1A**) showing significant differences ($F = 38.2$, $P < 0.001$) in their mean finishing times: (i) five were *responders*, with a mean time reduction of 7 min 54 s compared to the mean of their previous finishing times; and (ii) five were *non-responders*, increasing on their mean previous finishing time by 3 min 37 s.

Maximal Incremental Tests

When considering the whole group, the VO_2max recordings ($mL \cdot kg^{-1} \cdot min^{-1}$) obtained in the laboratory maximal incremental tests (L-UMTT) after the training protocols showed a significant decrease of 3.7% ($P = 0.05$) compared to the values obtained before the training started (**Table 1**). However, when the training groups were analyzed separately, VO_2max did not show significant differences ($P = 0.833$) *before* and *after* the training program in the MICT group, whilst a significant decrease of 7.2% ($P = 0.008$) was observed in the HIIT group. Moreover, there was greater variability in VO_2max after the training program in the HIIT group, which presented a larger CV (13.2%) and range (18.7 $mL\ O_2 \cdot kg^{-1} \cdot min^{-1}$) than the MICT group (CV = 9.8%; range = 13.7 $mL\ O_2 \cdot kg^{-1} \cdot min^{-1}$). **Figure 1B** shows that half the women in the MICT group increased their VO_2max, while the other half of the group decreased their VO_2max. By contrast, almost everyone (9 out of 10) in the HIIT group decreased their VO_2max.

Regarding the maximal incremental test performed in the field (F-UTTM), the whole group significantly increased ($P = 0.002$) the TTE in the 8th week of training compared to that recorded in the F-UMTT prior to the start of the training programs (**Table 1**). When the training programs were considered separately, the TTE significantly increased in both the MICT (4.7% increase) and HIIT (3.0% increase) groups (**Table 1**). Variability in this performance indicator after the training programs was similar in both groups, with almost the same CV (~13%) and range (~7 min). However, there were some differences between the groups in the responses, since three participants in the MICT group failed to improve their times, whilst only one from the HIIT group worsened on her previous times (**Figure 1C**).

Field Training Tests

Figure 2 shows the percentage variations in individual field tests performed to assess (i) the interval training power output in the 800-m series (MICT program) and in the 200-m and 400-m series (HIIT program; **Figure 2A**), and (ii) the long run pace over 8 km (**Figure 2B**).

The women in the MICT group showed varying improvements in their power output in the 800-m interval series. Approximately half of them increased their power output after the training program, while the other half did not increase or even decreased it. This was in contrast to the clear improvement in all the women in the HIIT group for both the 200-m and 400-m series, with mean increases of 9% and 20%, respectively.

The mean long run pace over 8 km showed a 2% to 3% non-significant decrease, i.e., less time was invested per km. Moreover, the analysis of individual results for this field test (**Figure 2B**) indicated that, overall, the women in the HIIT group showed a better response to training than those in the MICT group (78% vs 38% improved their pace).

DISCUSSION

Our study examined responses to two training programs involving different intensities and running volumes, both performed 3 days per week over 12 weeks. A global improvement in field performance was observed at the end of the training period for the two training groups. However, there were different inter-individual responses after the training period, with some participants showing improvements in performance indicators (*responders*), while others failed to exhibit positive changes (*non-responders*).

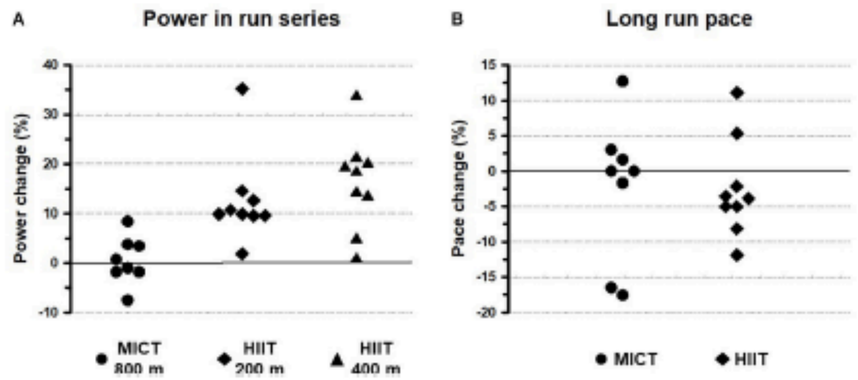

FIGURE 2 | Individual percentage changes *before* and *after* the training program in women participating in moderate-intensity continuous training (MICT) and high-intensity interval training (HIIT). **(A)** Percentage changes in power obtained in interval run series in the field *before* and *after* the training programs. **(B)** Percentage changes in the long run pace (8 km) in the field *before* and *after* the training programs.

Regarding the finishing times in the half-marathon, the MICT group exhibited a wider range in their responses, with more responders (70%) in this group than in the HIIT group (50%; **Table 1**). The fact that there were responders and non-responders in both groups (**Figure 1A**) indicates that the adaptive response to the training programs varied individually, even if the participants followed a standardized and supervised endurance training program with prescribed intensities based on their percentage of VO_2max. This finding in middle-aged women is in accordance with those of studies on young women (McPhee et al., 2010) and men (Vollaard et al., 2009; Scharhag-Rosenberger et al., 2010). These studies concluded that it is advisable to standardize exercise intensity using other measures related to performance power output, such as blood lactate, rather than the percentage of VO_2max, due to the inhomogeneous blood lactate responses obtained after prolonged endurance exercise at given percentages of VO_2max. This is especially relevant in advanced age, as has been reviewed by Lepers and Stapley (2016), who reported that VO_2max seems to be the parameter most altered by age, contrasting to exercise economy and the lactate threshold, which decline to a lesser extent with advancing age. Taking into consideration this variability in the responses, an individualized exercise prescription might be needed instead of standardized methods. Some proposals have been made, such as those based on kilocalories expenditure per week in relation to body mass (Weatherwax et al., 2016).

Regarding VO_2max, it must be noted that we found a decrease at the end of the training programs, which was significant in the HIIT group (**Table 1**). Moreover, all the participants in the HIIT group were *non-responders* for this performance indicator (**Figure 1B**), suggesting a worsening in performance. However, this could not be the case, especially at high loads, if other performance variables, such as running economy, were improved. Silva et al. (2017) reported that a HIIT program mediates a reduction in the energetic cost of running, allowing runners to achieve higher speeds at the end of the maximal incremental treadmill test without significant increases in the VO_2max. There is also some evidence that improvements in high-intensity aerobic performance are not strongly associated with improvements in VO_2max since low responders for one parameter are not necessarily low responders for another (Vollaard et al., 2009). Moreover, greater efficiency at moderate and high loads in a maximal progressive short effort could indicate the effectiveness of training, but its translation to a specific performance (e.g., half-marathon) is of less importance, since the speeds of running a half-marathon are lower than those at which the improvement has occurred.

Our results also indicated that focusing on other specific tests in the field could be a better tool in assessing the improvement in endurance elicited by training programs. Thus, in both groups, maximal incremental tests in the field showed that after the 12-week training period, most of the participants increased their TTE, exhibiting a homogeneous response (**Figure 1C**) and significantly higher mean times (**Table 1**). However, the two groups showed different behaviors in their responses for the interval series (power) and long run (pace) field tests (**Figure 2**). For both tests, there was a greater number of responders among the women in the HIIT group than in the MICT group. This could be due to the fact that the HIIT sessions of short-burst intervals interspersed with low-intensity recovery periods lead to a strong engagement of neuromuscular and musculoskeletal systems (improving power in 200-m and 400-m series), allowing individuals to run at high intensities with low lactate levels (increasing pace during long runs; see for review, Buchheit and Laursen, 2013). The heterogeneity in the responses and the different behaviors in the MICT and HIIT groups reported here for middle-aged women are consistent with those recently found for young males and females (Bonafiglia et al., 2016) and also with the findings of a multi-center comparison study of trainability by Williams et al. (2019) involving a big sample size with different ages and conditions.

The different individual responses to the training interventions, with some subjects as *responders* and others as *non-responders*, may be a consequence of a combination of two factors. First, all the women participating in this study were amateur runners with some level of previous training experience. This previous high or near maximal physical fitness could have affected the changes in the performance indicators analyzed in some participants, since diminished improvements in performance indicators such as VO_2max have been described in trained subjects enrolled in training programs, in contrast to the rapid increases observed in untrained individuals (Wenger and Bell, 1986). Second, responses to training might be highly individual, as has been recently described for HIIT by Astorino et al. (2018), who found that some participants showed meaningful increases in some performance variables, whereas others showed no changes in their previous values. Several anatomical, biochemical and physiological systems interact to influence sports performance and could account for this inter-individual variability to training. The individual differences in metabolic pathways could quantitatively increase or decrease the measured parameters and induce synergistic or antagonistic effects depending on the training protocol. For example, it is well known the human individual variation in skeletal muscle fiber-type proportion (Simoneau and Bouchard, 1989) which is highly correlated with sports performance (Costill et al., 1976). Other factor involved in the variability of the responses to training could be the metabolic and biomechanical specificity of each training program (Kenney et al., 2012). The different constraints imposed by MICT or HIIT would result in more or less evident changes in performance depending on the characteristics of each training schedule and the parameters assessed. This could explain finding more responders in the HIIT group in the interval run series (**Figure 2A**).

Our results provide further support for individualized exercise prescription to optimize workouts. Furthermore, our findings suggest that several performance indicators can be used to assess training programs. For instance, the analysis of continuous variables throughout a training process beyond maximal values could provide more sensitive information to determine specific adaptations in different training programs. This has been recently demonstrated by Garcia-Retortillo et al. (2019), who compared HIIT and MICT programs and observed that, despite improving markers of aerobic fitness to a similar extent, changes in cardiorespiratory coordination were specific for each training intervention. For endurance recreational runners, moderate continuous training with extensive aerobic loads is the most frequently used type of training (see for example, Fokkema et al., 2020). However, a huge amount of time is invested in training and the protocols are repetitive, increasing the risk of musculoskeletal injuries due to overuse (Dias-Lopes et al., 2012). In fact, one of the initial participants following MICT abandoned the study suffering from an injury. Conversely, high intensity training with low repetition not only reduces training time, but also decreases the risk of injuries due to overuse, as has been recently reported by Mallol et al. (2020). In the present work, we did not report any injuries in HIIT ruling out the possible increased risk of acute injury due to the greater intensity of the HIIT program.

The main strength of this study was the homogeneity of the group studied, i.e., middle aged women with previous amateur experience in running events. This population group is poorly studied and has become increasingly involved in amateur running events in recent years (van Dyck et al., 2017). The main limitation of the study was the small sample size of $n = 20$, with $n = 10$ in each training group. It would have been better to have a greater sample size, which, undoubtedly, would have rendered higher power to the conclusions and provided more sensitivity to detect significant differences in the eventual changes. Similar studies could be performed in the future in population groups with different genders and/or ages, as well as using participants with different levels of fitness (from sedentary to elite athletes). Our idea for future studies is to design experimental work that can identify in advance responders and non-responders with the aim of creating a pre-training schedule that can be modified to help non-responders improve their performance. In this sense, incorporating complex system approaches, such as those reported by Balagué et al. (2016) and Garcia-Retortillo et al. (2017) on cardiorespiratory coordination, will be of great value in assessing a strategic research framework for individual training prescriptions.

CONCLUSION

Two different training programs for a half-marathon, one based on high intensity and moderate training volume (HIIT) and the other involving moderate intensity and greater training distances and times (MICT), were compared in a group of amateur middle-aged women runners. A global improvement in the mean finishing time for the half-marathon and improvements in field performance indicators at the end of the training period, such as TTE, power in short-run series and long run pace, were observed in the two training groups. However, there were different inter-individual responses after the training period, with some participants showing improved performance (*responders*) and others failing to exhibit positive changes (*non-responders*). These different responses depended on the training group, with more heterogeneous results in HIIT group. As a future perspective, these findings could help running coaches and amateur running practitioners to modify workloads to optimize performance. Compiling data on individual measurements (such as anthropometrical, epidemiological, physiological, and those regarding to performance), a predictive model could be constructed with the goal of deciding the suitability of the training protocol to be applied. Depending on the runner's vital status, a MICT, HIIT or a mixed training model could be prescribed, optimizing runner's effort and time dedicated to training, which would decrease injury risk factors and improve training adherence.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Ethics Committee of the University of Barcelona (Institutional Review Board number, IRB00003099). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CJ and JT conceived and designed the study. JB and CJ conducted the experiments. JB, CJ, and JT analyzed the data and wrote the draft manuscript. JV, JM, GV, and TP corrected the draft manuscript and contributed the analytical tools. All authors read and approved the manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Artículo IV

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Volume *versus* intensity programme training for a half-marathon: haematological and biochemical parameters in middle-aged women

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Abstract

Half-marathon race is very popular among recreational runners with the most important increases in participation in the last years among the middle-aged population group and in women. The aim of our study was to determine the effects on haematological and biochemical plasmatic markers of two training programmes for a half-marathon, to be applied to middle-aged recreational female runners. Twenty women (40±7yr) followed two different training schedules: moderate intensity continuous training (MICT), based on running volume at intensities below 80% VO_2max, and high intensity interval training (HIIT), with less volume ran at 80%-100% VO_2max combined with uphill running and resistance training. Haematological parameters, plasma osmolality and several plasmatic markers of metabolic status, muscle damage, inflammatory and oxidative stress were measured at the beginning (S1) and end (S2) of the training and 24h after finishing a half-marathon (S3). With few exceptions such as for haematocrit, interleukin-6 and total antioxidant status, both training programmes had similar moderate effects at S2. However, the acute response after the half-marathon (S3) induced different alterations depending on the training programme. Higher decrease in lipid profile parameters in MICT groups and lower values in markers of damage and inflammation in HIIT group indicate that the intensity of the training determined the metabolic pathway and the substrate used as source of energy during the race and promoted a better skeletal muscle protection before acute exercise. Finally, a greater variability in MICT group in S3 for some plasma markers suggests a different inter-individual variability in the response to training.

Keywords

Half-marathon, recreational running, women, haematological parameters, plasma markers,

Introduction

Since the early 20th century running races covering approximately the half-marathon distance began to appear, although the first world records accepted of the official distance (21.097 km) by the Association of Track and Field Statisticians were recognised in 1960 for men (Quercetani 1961) and in 1971 for women (Magnusson 1972). Although half-marathon race is not included in the Olympic Games programme, it is very popular among recreational runners, as demonstrates the increase in popular races' participation over the last decades (Knechtle et al. 2016). Although it still exists, the gender gap has considerably narrowed over the years and, in some cases, female half-marathon finishers exceeded male's numbers (Running USA 2017). Regarding the age of the finishers, the study by Knechtle et al. (2016) on all the half-marathons held in Switzerland between 1999 and 2014 found that the mean age of men and women participants was approximately the same: 41 years for both genders. This rapid progression in women race participation has had important performance consequences and has been the result of specific training programmes leading to quick improvements.

Regarding performance, it is important to consider the influence derived from several well-known physiological differences between men and women, such as those dependent on the erythrocyte mass, body composition or the maximum oxygen consumption (VO_2max) (Joyner, 2017). For example, the lineal relationship described between haemoglobin mass and VO_2max in humans (Schmidt and Prommer 2010) could stand for the differences in VO_2max values reported for a cohort of elite American female and male marathon runners: 67.1±4.2 $mL·kg^{-1}·min^{-1}$ versus 74.1±2.6 $mL·kg^{-1}·min^{-1}$ (Pate and O'Neill 2007). However, the loss of maximal strength and rate of force development after a half-marathon run was found to be similar between men and women, being associated these force capacity reductions with central and peripheral fatigue (Boccia et al. 2018). Interestingly, some performance responses appear to favour female recreational runners, as it is the case of the reported differences in the running strategy and the control of fatigue: women are much better in rhythm control, suffering fewer catastrophic decelerations during the second half of marathon races (Deaner et al. 2015). There are also known differences between women and men regarding metabolism during long-term aerobic effort. For example, at the same relative intensity, during the last part of the exercise, women oxidized 47% more plasma FFA than men (Roepstorff et al. 2002). Women also show less dependence on liver and muscle glycogen during the endurance effort, presenting a greater volume of intramyocellular lipids, which is attributed to their higher oestrogen levels (Devries 2016). Regarding training, plasmatic determinations reported in a group of women aged 25 to 35, after a 9-week training (3 times a week), sowed a 7.6% decrease in total cholesterol values, 8% increase in high-density lipoproteins and no changes in low-density lipoproteins, haemoglobin, serum glucose and triglycerides levels (Kyröläinen et al. 2018).

Over the last decade some studies have evaluated different plasmatic markers and haematological parameters after a half-marathon run, most of them centred on studying a young male population. Thus, plasmatic inflammatory and immune response markers (Reihmane et al. 2013) and several circulating miRNAs (de Gonzalo-Calvo et al. 2015, Fernández-Sanjurjo et al. 2020) were reported to increase in an exercise dose-dependent manner. Cardiac injury markers such as troponin, creatine kinase and myoglobin also increased after the half-marathon race in men (Lippi et al 2012), showing no differences between sexes, when women were also included in the experimental design (Jassal et al. 2009). In contrast, sex-specific differences in activation of inflammation-related pathways and in the regulation of leukocyte genes in response to acute exhaustive exercise were reported by Abbasi et al. (2016). Lippi and co-workers reported the kinetics of the variation from the baseline (3 h to 24 h) of several muscle damage plasmatic markers (Lippi et al. 2008) and haematological parameters (Lippi et al. 2010) after a half-marathon race in an age-heterogeneous male sample. These authors also included females in the experimental design of a more recent study (Lippi et al. 2014) but did not analysed separately male and female data.

All the above-mentioned research shows the interest aroused by the biochemical and physiological changes derived from running a half-marathon race. However, to our knowledge, there is a lack of studies tracking these changes before and after the training period for the half-marathon and comparing to the post-race recovering period. In an attempt to fill this gap, we aim to analyse the long-term response to a 12-week training period of two groups of premenopausal amateur running women subjected to two training programmes for a half-marathon: one protocol based on a high intensity intermittent training (HIIT) and another based on a moderate intensity continuous training (MICT). Hypothetical differences between programmes, in biochemical plasma markers and haematological parameters, after the acute insult elicited by the half-marathon run are also evaluated.

Material and Methods

Subjects

Twenty healthy female master recreational runners (age range between 35 and 45 years) volunteered to participate in this study. The participants were recruited from different running clubs in the city of Barcelona (Spain) and had the following anthropometric measures (mean ± SD): age 40±7 years, weight 61±7 kg, height 167±6 cm and body mass index 23±3. The volunteers had to satisfy the following criteria to be eligible for the study: to be regular runners with minimum training routines of 5 h and 3 days per week and to have previous experience in half-marathon running, to be pre-menopausal, non-smokers, to have no injuries and not to take any medication (including oral contraceptives).

Subjects were randomly assigned to two training groups of ten runners. One group followed a moderate-intensity continuous training (MICT) programme, with a high-volume and low-intensity training protocol. The other group enrolled in a high-intensity interval training (HIIT) programme, completing a low-volume and high-intensity interval running protocol with bodyweight resistance exercises. There were no significant differences between groups in neither performance nor anthropometric parameters. The participants signed an informed consent form and were free to withdraw from the experimental protocol at any time. The study was developed in accordance with the Declaration of Helsinki concerning the ethical principles of human experimentation and was approved by the Institutional Ethics Committee of the University of Barcelona (Institutional Review Board number, IRB00003099).

Training programmes

After one-month rest in August, participants initiated the training period in September and finished after 12 weeks in December, involving every week 3 non-consecutive training sessions. The details of each training programme have been published elsewhere (Bonet et al. 2020a). Briefly, the MICT programme was based on Galloway and Galloway (2012). Weekly, it consisted of 2 days of continuous running (40 min and 60 min) alternated with one day of long-distance running (from 12 km to 25 km) and 800-metre intervals. The HIIT programme was designed to reduce training volume and increase training intensity (Bonet et al. 2020a). Weekly, it consisted of one session of long-distance running (from 8 km to 16 km), one session of interval running (200-m and 400-m series), and a third session that alternated between an uphill run and a fast run with a circuit 12 stations of bodyweight resistance exercises performed at maximum intensity (Klika and Jordan 2013). In order to improve anaerobic power and increase the efficiency of using elastic energy, at the end of the third session the participants performed 50–m sprints. The women enrolled in the HIIT run 301 km, which was a 21% less distance than that run by the MICT group (383 km). Regarding the training time, HIIT participants invested 33 h and 26 minutes, a 17% reduction in time than the MICT group (40 h and 30 minutes). After the training programmes, all the women participated in the same half-marathon race held in Vilanova i la Geltrú (Spain), located at sea level on the Mediterranean coast (41°13′ 27″ N, 1°43′ 33″ E).

Blood sampling and preparations

All the venous blood samples were taken by conventional clinical procedures from the antecubital vein and using EDTA as anticoagulant. Blood samples (S) from each participant were collected at three different temporal points: S1 was taken the week before the training programmes began, S2 was obtained 48 h before the half-marathon run, and S3 was withdrawn 24 h after finishing the race. An aliquot of freshly blood was separated for haematological determination. White blood cells (WBC), red blood cells (RBC) and platelet (PLT) counting, haemoglobin concentration and the haematimetric indices (mean corpuscular volume, MCV; mean corpuscular haemoglobin, MHC; mean corpuscular haemoglobin concentration, MCHC) were obtained in a haematological analyser (Celltac α MEK-6318K, Nihon Kohden Europe GmbH, Rosbach, Germany). The remaining blood material (≈ 10 mL) was immediately centrifuged at 3,000 rpm during 10 min for plasma removal. An aliquot was used for plasma osmolality measurement in a micro osmometer (Model 3300, Advanced Instruments Inc., Norwood, MA, USA) and the remaining plasma aliquots were rapidly frozen and stored at -80°C for later biochemical analysis.

Biochemical assays

All samples were analysed in triplicates and the mean of the three values was used for statistical analysis. Plasma ion determination was done in an electrolyte analyser (ISElyte-X9, Tecil, Barcelona, Spain). Protein content was spectrophotometrically assayed using bovine serum albumin as standard according to Lowry et al. (1951). Routine biochemical methods were used for the determination of total cholesterol, triacylglyceride (TAG), high-density lipoprotein (HDL) and low-density lipoprotein (LDL) was calculated using the formula of Friedewald et al. (1972).

Assay commercial kits from Elabscience (bioNova, Madrid, Spain) were used for plasma albumin, glucose, urea, aspartate and alanine aminotransferases (AST and ALT) and gamma-glutamyl transferase (GGT) determination. Colorimetric commercial kits ab235627 and ab196994 from Abcam Inc. (Cambridge, MA, USA) were used to measure plasma bilirubin and aldolase, respectively. Plasma creatine kinase (CK) activity was determined spectrophotometrically using a commercial test kit (ABX A11A01632, Montpellier, FR). C-reactive protein (CRP) was measured using an enzyme-linked immune sorbent assay system (ELISA-PENTRA 400, Horiba ABX, Montpellier, FR).

Total antioxidant status (TAS) was measured spectrophotometrically using a commercial kit (Randox NX2332 Crumlin, UK). Superoxide dismutase (SOD) activity was measured spectrophotometrically at 550 nm using a commercial Ransod kit from Randox (catalogue no. SD 125, Crumlin, UK). The activity of glutathione peroxidase (GPx) was assayed by a spectrophotometric technique at 340 nm using a commercial Ransel kit from Randox (catalogue no. RS 505). The activity of glutathione reductase (GR) was measured with a spectrophotometric procedure at 340 nm using a commercial GR kit from Randox (catalogue no. GR 2368). Plasma total glutathione (TGSH) and oxidized glutathione (GSSG) measurements were determined following Tietze (1969). A medium containing perchloric acid at 5% (w/v) was used to precipitate the proteins from the aliquots for glutathione assay. To measure TGSH content, samples were centrifuged for 1 min at 13,000 g after neutralization with potassium hydrogen carbonate (0.76 M) and a supernatant aliquot was incubated for 15 min at 30°C in a microtiter plate with a reagent solution containing NADPH (1.68 mM) and 5,5'dithio-bis (2-nitrobenzoic acid) (0.7 mM). A kinetic analysis was performed at 412 nm after the addition of 20 U·mL-1 of glutathione reductase. GSSG content was measured adding 2-vinylpyridine, for a final concentration of 5% (v/v), before the neutralization step in order to inactivate the sulfhydryl groups. Then, the assay continued with the same steps followed for TGSH measurement. TGSH and GSSG concentrations were calculated based on calibration curves made with commercial standards. Reduced glutathione (GSH) was calculated as GSH=TGSH-GSSG and percent oxidized glutathione (%GSSG) as the percentage of the ratio GSSG/TGSH.

Statistical analysis

After checking normality (Kolmogorov-Smirnov test) and homoscedasticity (Levene test), data were analysed using one-way ANOVA with repeated measures to compare the values obtained at the three different sample points (S1-S2-S3) within each training programme. *Post hoc* multiple comparisons after ANOVA testing were performed using the Holm-Sidak method. *P*-values are given throughout the text, tables and figures, considering significant statistical differences at $P<0.05$. The results are reported in the text and tables as mean ± SD, unless otherwise indicated. In the box-and-whisker plots, the box represents the interquartile range and shows the first and third quartiles separated by the median. The mean is represented by a black dot, and whisker ends represent the minimum and maximum values. All data were statistically analysed using SigmaPlot 11 (Systat Software, Inc., San Jose, CA, 2008-2009).

Results

With few exceptions, such as for haematocrit and interleukin-6, both training programmes had similar effects on the parameters analysed after a 12-week period of training (S1 vs. S2). However, the acute response after the half-marathon (S3) induced different alterations in blood markers of metabolic status, muscle damage, inflammation and oxidative stress depending on the training programme followed. This indicates a different response to an acute maximal exercise, such as a half-marathon run, depending on the nature of the training exercise, its intensity, running volume and duration.

Haematological parameters

Direct measures involving red blood cell count and haemoglobin concentration did not show statistically significant differences because of neither the training programmes (S2) nor the half-marathon run (S3) (Figure 1A and 1B). However, in MICT group, haematocrit significantly increased after the training programme and significantly decreased 24 h after the half-marathon, when compared to its pre-race values (Figure 1C). These haematocrit changes were not observed in the HIIT group, which values remained without significant alteration in the three sampling time points.

Derived measures (Table 1) from red blood cell count and haemoglobin concentration (mean corpuscular concentration, MCH), and haemoglobin concentration and haematocrit (mean corpuscular haemoglobin concentration, MCHC) showed great significant differences ($P<0.001$) before and after MICT programme but not after HIIT. However, the half-marathon run elicited significant decreases in MCH and MCHC in both training programmes. Mean corpuscular volume (MCV) only showed statistically significant difference ($P<0.05$) in HIIT, between post-race samples (S3) and pre-training values (S1).

After the half-marathon, white blood cell counts increased, but only significantly ($P<0.05$) in HIIT group, whilst platelet number experienced a significant decrease in both groups (Table 1).

Plasma solute concentrations

Figure 2 shows the total measured plasma osmolality and plasma concentrations of the main solutes. Because of both training programmes, plasma osmolality was significantly reduced (P<0.01). Moreover, also for both training groups, samples obtained 24 h after the half-marathon (S3) showed significant decreases when compared with values obtained in pre-race (P<0.05) and pre-training (P<0.001) sampling points (Figure 2A). Plasma sodium and chloride concentrations increased in MICT group when comparing S3 *vs* S2 sampling points (P=0.092 in sodium and P<0.05 in chloride) but showed no significant changes in HIIT group (Figure 2B and 2C). Conversely, plasma phosphate concentration decreased from S2 to S3 sampling points: significantly in MICT group (P<0.01) and slightly in HIIT (P<0.081). Moreover, samples obtained 24 h after the half-marathon run showed statistically lower significant plasma phosphate values than the pre-training baseline (S1) for both groups (Figure 2D). Box plots showing glycaemia in S3 indicate a great range of plasma glucose concentrations with means tending to decrease in both training groups (Figure 2E). This decrease was significant (P<0.05) when considering the *post hoc* S1 *vs* S3 comparison in MICT group. Urea plasma concentration decreased gradually and significantly from S1 to S3 time sampling points in women following MICT programme, whilst no statistical differences were observed between the three samples for HIIT (Figure 2F).

Liver and lipid panel

Although there was a trend for decreasing from S1 to S2 values, the training modality had no significant effect on any parameter related to liver or lipid panels, as is deduced from the absence of statistical differences after both MICT and HIIT programmes (Table 2). Moreover, the half-marathon run (S3) neither did elicited any alteration in liver enzymes measured in plasma (AST, ALT and GGT) nor in total plasma bilirubin. However, when S3 results were compared with both S1 and S2, stark significant decreases in total plasma protein and albumin content, as well as in most of the lipid panel measures, were evident. It is of interest to note that the most striking differences between S3 and S1-S2 values were obtained in the MICT group. The significant decreases in plasma total protein and albumin concentration ranged from 24% to 30% in MICT group, which contrasted with the 11% to 17% decreases in HIIT. Similarly, total cholesterol and LDL decreases ranged from 30% to 45% in MICT whilst the diminution in S3 values was from 16% to 24% in HIIT. Finally, TAG plasma contents showed significant lower S3 values in MICT (with $P<0.001$ *vs* S1 and $P<0.01$ *vs* S2) contrasting with an absence of statistical difference in HIIT.

Muscle damage and inflammation markers

Neither MICT nor HIIT programmes had any effect in creatine kinase plasma levels, since no statistical differences were found between S1 and S2 in any case. However, 24 h after the half-marathon run, significant elevations of this muscle damage marker were evident in both groups: in both cases the post hoc multiple comparison test indicated an statistical significance ($P<0.05$) between S3 and S1 or S2 (Figure 3A). Moreover, the increase in the mean, when compared with pre-race (S2) values, was different between the training groups, i.e., more pronounced in MICT (153% increase) than in HIIT (63% increase). The aldolase levels did not present significant differences between sample time points in any training group (Figure 3B). C-Reactive protein inflammation marker showed a similar behaviour than creatine kinase, with no significant differences between S1 and S2 and significant elevated values in S3 that were more pronounced in MICT group (Figure 3C). When a *t*-test was run for comparison between MICT and HIIT in S3 values, the higher values found in MICT, both for CK and CRP, resulted statistically significant with $P=0.043$ and $P=0.039$, respectively (Figure 3A and 3C, *p*-values not shown). Interleukin-6 presented significant increases 24 h after the half-marathon (S3) in both groups when compared to baseline (S1). However, it showed a different behaviour in pre-race (S2) values depending on the training programme: whilst there were no difference between S1 and S2 in MICT, S2 values showed a marked significant increase ($P<0.001$) in HIIT (Figure 3D). Finally, it is worthy to note that, in all muscle damage and inflammation parameters measured, the MICT group presented a greater variability in S3 values than HIIT, as is deduced from the differences in the box plots sizes.

Oxidative stress-related parameters

Total antioxidant status (TAS) showed a trend to increase after MICT and a significant (P<0.05) higher value after HIIT, which reverted to baseline values 24 h after the half-marathon (Table 3). Among the antioxidant enzymes, no statistical differences were found between the three time sampling points except for SOD activity in MICT group, were a significant increase was evident 24 h after the half-marathon run. After the training period, neither MICT nor HIIT programmes had a significant effect in the levels of either total (TGSH) or reduced (GSH) glutathione. However, both parameters were highly increased 24 h after the half-marathon run with statistical significances between P<0.01 and P<0.001. A pronounced decrease after both training programmes was evident in oxidized glutathione (GSSG), being statistically significant (P<0.01) only in HIIT group, and in %GSSG, with significant (P<0.05) reductions in both exercise programmes. The half-marathon run provoked huge significant increases (P<0.01 and P<0.001) in either TGSH, GSH or GSSG. Regarding the ratio %GSSG, 24 h after the half-marathon run a marked but not statistically significant increase from pre-race values was evident in both groups. It is notably the great dispersion found in this ratio, as deduced from the high standard deviation figures.

Discussion

The results presented in this study contribute to increase knowledge on the haematological and biochemical plasmatic alterations occurring after an acute endurance exercise insult such as a half-marathon run. Several studies in the past decade assessed the changes elicited by a 21-km run in haematological parameters, muscle damage, oxidative stress and inflammation plasmatic markers in different age groups (mainly men) with different fitness conditions (Duca et al. 2006, Lippi et al. 2008, 2010, 2012, 2014, Jassal et al. 2009, Reihmane et al. 2013, Gomes et al. 2014, Nimelä et al. 2016a, 2016b, Martinez-Sanchez et al. 2017, Withee et al. 2017, Lynn et al. 2018, Wiewelhove et al. 2018). The relevance and the novelty of our study is that we analysed haematological parameters and biochemical plasmatic markers in a poorly studied age population group: middle-aged women training at a recreational level. Moreover, this study incorporates the evaluation of the effects on haematological and biochemical plasmatic parameters of two different 12-week training programmes based on different strategies regarding the training intensity and volume of running. Thus, this experimental approach allows to compare not only the haematological and biochemical changes taking place 24 hours after an acute endurance exercise trained with two different strategies, but also the effects of both training programmes on the analysed markers.

Haematological parameters

Given the absence of statistically significant differences in RBC and haemoglobin concentration after the 12-week training period in both training programmes compared to their baseline pre-training values (Fig. 1A, 1B), it is surprising the significant increase in haematocrit after MICT (Fig. 1C). We can only speculate for an increase in blood volume because of a more endurance-oriented training programme (MICT) in contrast to the training based on intensity performed by HIIT group, where an increase in haematocrit was not observed. A greater relative increase in erythrocyte volume (MCV) in MICT, which matches the significant decreases found in haematimetric indices related with corpuscular haemoglobin (MCH and MCHC, Table 1), could support this hypothesis. In fact, hypervolemia is a hallmark of endurance training and is manifested by elevations in plasma volume concomitant with increases up to 10% in the corpuscular volume of the red blood cells (Montero and Lundby 2018). This adaptation has been recently described in team sports (Saidi et al. 2019), being confirmed in aerobic efforts after intermittent activities (Rhibi et al. 2019), and could be accompanied by an increase in performance (Warburton et al. 2004, Zouhal et al. 2007, Pavón and Lavie 2017). The haematocrit elevation after 12 weeks of MICT is reverted to baseline values 24 h after the race, resulting in a significant difference when post- and pre-race values are compared. This significant reduction was not observed in HIIT group. We would propose exercise-induced haemolysis derived from footstrike during running

(Telford et al. 2003), RBC oxidative damage (Smith 1995) or perturbation of osmotic homeostasis (Green et al. 1991) as possible causes for the post-race haematocrit decrease in MICT group. However, the absence of statistical differences in RBC and haemoglobin concentration between pre- and post-race values advise to consider this hypothesis with caution. Thus, in an attempt to explain the differences that the race had on haematocrit between both training groups, we can only speculate that, because of the repeatedly exposition to intensity activities, HIIT group was exposed to a greater peripheral impact that could have developed adaptive mechanisms regarding tissular filtration allowing to face a high intensity effort without affecting the haematocrit.

Our results show in both training programmes a significant decrease in both MCH and MCHC indices measured 24 h after the half-marathon run compared to baseline values (Table 1), which is compatible with the greater erythrocyte volume found after the race (significant for HIIT group). These results match previous half-marathon studies on a similar age group sample of men and women and on male sub-elite athletes, which found increases in RBC distribution width 20 h post-race (Lippi et al. 2014) and 7% increases in reticulocyte mean corpuscular volume in samples analysed 48 h after the competition (Duca et al. 2006). Thus, the half-marathon, as an acute strenuous exercise, would mean a strong stimulus for reticulocyte release, increasing the red blood cell variation in volume and size.

Regarding the WBC, no statistically significant changes were observed throughout both training periods, although the clear decreasing trend seen in Table 1 could be a consequence of an increase in plasma volume. The higher WBC found 24 h after the half-marathon (significant for HIIT group) was also observed in other running studies with no agreement between whether there are differences in the increase depending on the type of effort performed (Schwane et al. 1983, Bobbert et al. 1986, Smith et al. 1989). This increase in WBC after prolonged exercise may be indicative of neutrophil marginalization or inflammation secondary to tissue destruction as suggest other studies. Duca et al. (2006) found a 62% increase in number of polymorphonuclear neutrophils just after finishing a half-marathon, which reverted after 48 h. After a high intensity effort, an increase in circulating white blood cells has been observed up to 12 hours, with certain differences in leukocytosis depending on the terrain in which the exercise is performed (Pizza et al., 1995). Our results, obtained after a half-marathon run performed at a nearly maximum effort and through a varied terrain, show an increase in circulating white blood cells lasting up to 24 hours (Table 1). This increase is higher and significant in HIIT group. Based on these data, it would seem that the type of training would influence the magnitude of the response, being greater in those who have performed a type of higher intensity loads, similar to what found by Pizza et al. (1995).

No differences were found in platelet counts because of any of the training programmes, but significant decreases were evidenced after the half-marathon in both training groups (Table 1). Similar findings were found 24 h after finishing a marathon in adolescents (Traiperm et al. 2013) but no changes were reported by Lippi et al. (2014) 20 h after a half-marathon run. However, Lippi et al. (2018), in another half-marathon study where they investigated the acute effects on various parameters related to blood coagulation in a group of 33 middle-aged males, reported an increase in prothrombotic activity in the third hour post-exercise. Regarding the specific effect on platelets, there are discrepancies between different studies depending on several factors such as the degree of training, the existence of previous pathology and the type of effort made (Hvas and Neergaard-Petersen, 2018). Considering our results, it is noteworthy the finding that, after 24 h, a prolonged and strenuous effort such as a half-marathon seems to be an stimulus powerful enough to induce a 14% reduction in platelet counts, when compared to the pre-race values, regardless the training programme followed. This response could be the consequence of an adrenergic stimulus developed especially in the final phase of the race, generating prothrombotic conditions that affect the platelet phase of coagulation with greater and better adhesion and a certain pro-activation environment of the platelet mass. This could facilitate the repair of the injured parts of the endothelium triggering a local response aimed to increase oxygen supply after platelet activation.

Plasma solute concentrations

It is well known that exercise promotes a stimulus, even during the effort itself, on antidiuretic hormone and aldosterone secretion aimed to compensate the water lost by sweating and filtration in the active tissues due to the vasodilation produced by the metabolites released during muscular activity (Luger et al. 1988). This effect would collaborate to increase plasma volume resulting from endurance training adaptation and could explain the significant reduction in osmolality observed after both training programmes (Figure 2A). Although no significant differences were found after 12-week training in the major components of plasma osmolality (i.e., sodium, chloride, glucose and urea concentrations, Figures 2B-2F), non-significant 5.2% to 6.8% (MICT) and 4.6% (HIIT) reductions in plasmatic total protein and albumin levels after training protocols could partially afford for these osmolality decreases after training regardless of the group (Table 2). However, after the acute exercise exposure to the half-marathon, a different response was observed between MICT and HIIT groups. Thus, women following MICT programme showed a two-fold greater percentual decrease between S2 and S3 of that shown by HIIT group in plasmatic osmolality and total protein and albumin circulating levels (Figure 2A, Table 2) and also greater significant decreases in plasma phosphate, glucose and urea concentrations (Figures 2D-2F). Changes in albuminemia have been related to acute inflammatory processes in certain pathologies (Soeters et al. 2019), which in our study seems to be caused by the insult produced by the half-marathon run, cursing in an increase in vascular permeability as a reaction to tissue injuries. Under this premise, MICT group tolerated worse the acute exercise effort than HIIT. The significant increase in chloride plasma concentration observed in MICT group, which contrasts to the absence of changes in HIIT (Figure 2C), adds more evidence to this reasoning, since it has been shown that the total and extracellular content of water, sodium and chloride of the muscle increases after an injury that promotes an inflammatory response (Bergstrom et al. 1987).

The significant decrease in plasma osmolality 24 h post-race in both training groups is in accordance with the significant 3.8% increase in plasma volume change reported by Lippi et al. (2008) in a population of middle-aged recreational male runners after 24 h of a half-marathon race. Although reported after extremely severe and prolonged exercise sessions (Hoppel et al. 2019), particularly in over hydration conditions due to excessive fluid intake, signs of exercise-associated hyponatremia seem not to be present in our study. In fact, despite the plasma osmolality is still low 24 h after the race, the concentration of chloride and even sodium in the plasma were higher than in control conditions, namely in the MICT group. This seems to suggest that the more extensive exercise regimen followed by MICT group during the training sessions predisposed the middle-aged women to deal more adequately with the stress associated to the sweating-related loss of water and micronutrients during the race and during the recovery period (Rosner et al. 2007).

Liver and lipid panel

Although the significant reduction in plasma albumin concentration after the half-marathon could suggest disturbed liver cell integrity, no statistical differences were found in any of the other liver panel biochemical markers (Table 2). These results lead us to the conclusion that neither MICT nor HIIT programmes had any injury effect on liver cells and that no hepatic damage was evident 24 h after finishing the half-marathon. Accordingly, since bilirubin levels did not show any alteration, neither as a consequence of training nor especially after the half-marathon run, hypothetical haemolysis caused by structural changes in the red cell membranes (Wu et al. 2004) should be ruled out. Regarding the hepatic markers, Nimelä et al. (2016), in a study population of six recreational runners (four men and two women) covering a wide age range, found that the post-race values after 48 h remained slightly higher for AST and ALT and unchanged for GGT. Statistical differences were reported by Lippi et al. (2008) in AST after 24 h in a middle-aged group of 15 men. The differences in the characteristics of the studied populations could explain some of the contrasting results obtained by these previous investigations.

Training programme had no effect in any of the plasmatic markers of the lipid panel, since no significant differences between S1 and S2 sampling points were observed neither in MICT nor in HIIT groups (Table 2). However, the long-term maximum effort elicited by the half-marathon run promoted important changes in circulating lipid metabolism markers but with a different magnitude depending on the training programme followed. Thus, total cholesterol was reduced by 30% in MICT but a lower 16% in HIIT, while LDL decreased by 36% in MICT and 24% in HIIT. More consistent differences were found in plasmatic HDL and TAG levels, which showed significant statistical decreases of 10% (HDL) and 40% (TAG) in MICT, contrasting with the absence of significant statistical changes in HIIT. These results indicate that the intensity of the training determined the metabolic pathway and the substrate used as source of energy during the race, affecting the 24-h post-race lipid profile. This finding agrees with previous studies carried out in other sport disciplines (Sgouraki et al. 2004) and in middle-distance and marathon runners (Välimäki et al 2016) where there was suggested that the effect of an acute bout of maximal endurance exercise on lipid and lipoprotein parameters may be related to different training histories.

Muscle damage and inflammation markers

In agreement with data previously published by others on acute variation of muscle damage and inflammatory biochemical markers after a half-marathon run (Reihmane et al. 2013, Lippi et al. 2008, Niemelä et al. 2016a, 2016b, Withee et al. 2017, Lynn et al. 2018, Viewelhove et al 2018), our results suggest that both groups of middle-aged women engaged in this study, exhibited signs of muscle damage and an inflammatory response after the half-marathon (Figure 3). In fact, even though both groups started from non-different post-training conditions (S2) when compared to pre-training (S1), the physiological impact of the run motivated the increase in CK, CRP and IL-6 that are compatible with a condition of exercise-induced muscle damage that has already been described elsewhere (Douglas et al. 2017, Peake et al. 2017). Considering the delayed kinetics of plasma CK appearance in the plasma after exercise-induced muscle damage, it can be hypothesized that biochemical analysis performed later in the time-course of recovery, namely at 48 h or 72 h may evidence higher levels of CK. In the context of the present paper, it is interesting to note that in the women that trained the MICT programme the half-marathon had a greater impact than in those who trained HIIT. When running a *t*-test between MICT and HIIT for S3 values, two markers of damage and inflammation presented statistically significant higher values in MICT with P=0.043 for CK and P=0.039 for CRP (Figure 3A and 3C, *p*-values not shown). This seems to suggest that the higher intensity of the pre-race training sessions performed by HIIT group promoted a better skeletal muscle adaptation to this particular physiological constrain. Regarding muscle damage and inflammatory response, skeletal muscle is able to adapt to systematic strength training sessions alleviating the impact of a subsequent harmful stimuli, which is known as the repeated bout effect (Hyldahl et al. 2017). Thus, considering the oscillating trajectory of the half-marathon with continuously and aleatory ups and downs, it is expectable that strength training routines associated to HIIT, namely the involving eccentric exercise, promoted a repeated bout effect that protected more the HIIT group compared to the MICT particularly for the eccentric impact of the race.

Figure 3 also shows a greater variability (larger box plots) in MICT group 24 hours after the race (S3) for all studied muscle damage and inflammation plasma markers. This finding indicates a different behaviour in the acute response to exercise depending on the intensity and volume of running trained and is in accordance with the inter-individual variability found in some performance and physiological indicators in response to these training programmes (Bonet et al. 2020b).

Oxidative stress-related parameters

Data from the present study highlight that although in opposite “directions”, both training regimens and the half-marathon modulated the redox “environment” of the participants. In fact, as can be depicted from Table 3, participants from both MICT and HIIT regimens increased their total antioxidant capability, evaluated by TAS and observed by the increase in the levels of GSH and decreased levels of %GSSG. Of note is that this redox modulation toward a more reductive environment was more evident in HIIT than in MICT (i.e., TAS and %GSSG), which probably relies on the specific features of both training regimens.

Unfortunately, there is a lack of data to support from a mechanistic point of view the distinct impact of both training methods regarding oxidative stress. Moreover, it is also very relevant that, even 24 h after the half-marathon race, the levels of GSH persist elevated when compared to baseline (S3 vs S2). This finding contrasts with the total reversion after 24 h to baseline values reported for other oxidative stress indicators (Withee et al. 2017). From our results, it seems that the race prone a condition of increased oxidative stress that was maintained in both groups even after 24 h. Considering that the evaluation of the glutathione levels was performed in plasma, eventually a significant enhanced oxidative stress at tissue level motivated the exportation of GSH from the liver to the muscle to cope the fall in skeletal muscle antioxidant capacity. Since the oxidative stress-related parameters were evaluated 24 h after the race, it is also possible that some of the levels will be related to the condition of muscle damage, previously described. In fact, increased production of oxygen reactive species and concomitant enhanced oxidative stress conditions are considered as key mechanistic steps in the pathophysiology of exercise-induced muscle damage (Thirupathi and Pinho 2018). Moreover, the excessive release of pro-inflammatory cytokines such as IL-6 (Figure 3D) can increase the production of reactive oxygen species and trigger oxidative stress in some tissues (di Penta et al. 2013). Hypothetically, one can suggest that the increased activity of SOD (S3 vs S2) in the MICT when compared to HIIT may be associated to a more “fragile” condition of these participants after the race and to a lower phenotype adaptation prone by each training regimen regarding muscle damage.

In summary, with few exceptions such as for haematocrit, IL-6 and total antioxidant status, our results indicate that both training programmes had similar moderate effects on the parameters analysed after a 12-week period of training in premenopausal women who have followed two different training programs for a half-marathon. However, the acute response after the half-marathon, measured after 24 hours, induced a temporary state of fatigue-related alterations in recovery and stress as well as in blood markers of muscle damage, inflammation, oxidative stress and metabolic status (urea and lipid profile), with differences depending on the nature of the training exercise, its intensity, running volume and duration. Training based on high intensity, incorporating strength exercises with their own body weight, could lead to a better adaptation at the time of competition given its repeatedly exposition to higher rates of oxygen consumption and the use of anaerobic metabolism during intense exercise bouts, providing some advantage and a more inter-individual homogeneous response before muscle damage and inflammation.

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Figure captions

Figure 1. Haematocrit (A), haemoglobin concentration (B), and (C) red blood cell counts values at three different sampling time points: before (S1) and after MICT or HIIT programmes (S2), and 24 h after the half marathon race (S3). The three asterisks show the statistical significant differences (P<0.001) between each pair of sampling time points. The lines and dots inside the boxes represent the median and the mean, respectively, and the whisker ends the minimum and maximum values. MICT: moderate-intensity continuous training; HIIT: high-intensity interval training.

Figure 2. Plasma osmolality-related measurements at three different sampling time points: before (S1) and after MICT or HIIT programmes (S2), and 24 h after the half marathon race (S3). A: measured osmolality. B: sodium, C: chloride, D: phosphate, E: glucose, and F: urea. Asterisks show the statistical significant differences between each pair of sampling time points: *, P<0.05; **, P<0.01; and ***, P<0.001. When *almost* significant differences were obtained, the *p*-value is indicated. The lines and dots inside the boxes represent the median and the mean, respectively, and the whisker ends the minimum and maximum values. MICT: moderate-intensity continuous training; HIIT: high-intensity interval training.

Figure 3. Plasma muscle damage and inflammation markers at three different sampling time points: before (S1) and after MICT or HIIT programmes (S2), and 24 h after the half marathon race (S3). A: creatine kinase, B: lactate dehydrogenase, C: aldolase, and D: C-Protein reactive. Asterisks show the statistical significant differences between each pair of sampling time points: *, P<0.05; and **, P<0.01. The lines and dots inside the boxes represent the median and the mean, respectively, and the whisker ends the minimum and maximum values. MICT: moderate-intensity continuous training; HIIT: high-intensity interval training.

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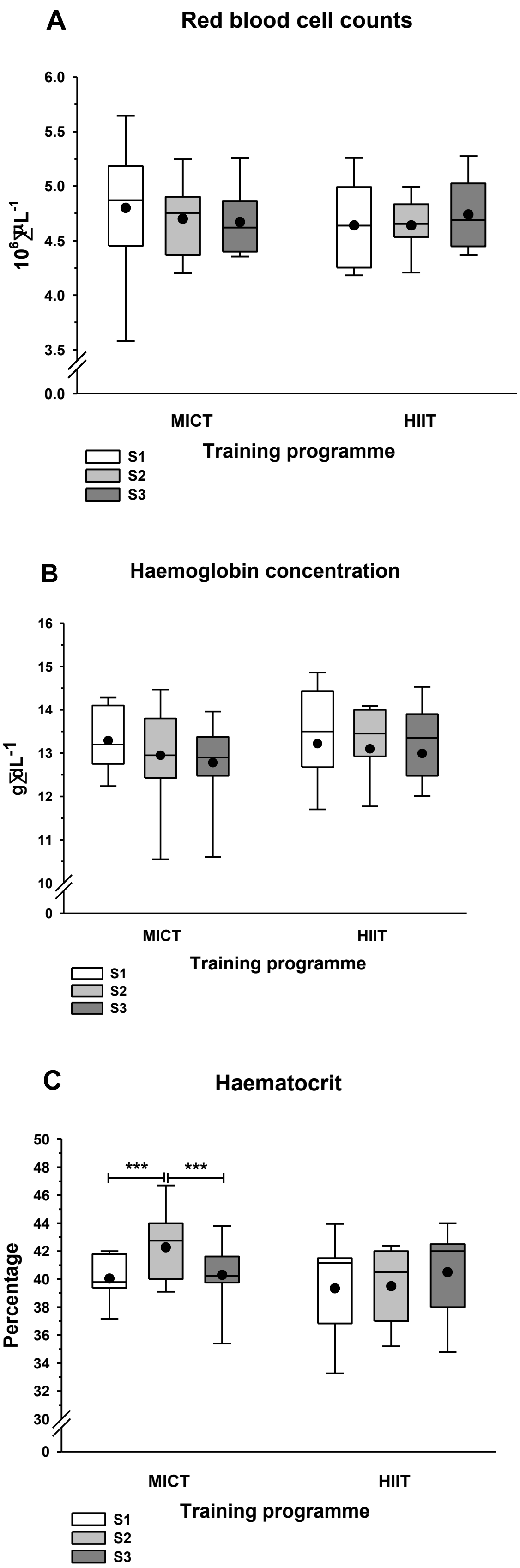
A
Red blood cell counts
6.0
5.5
5.0
4.5
4.0
3.5
0.0
MICT
HIIT
Training programme
S1
S2
S3
B
Haemoglobin concentration
16
15
14
13
12
11
10
0
MICT
HIIT
Training programme
S1
S2
S3
C
Haematocrit
50
48
46
44
42
40
38
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Percentage
MICT
HIIT
Training programme
S1
S2
S3

Figure 1.

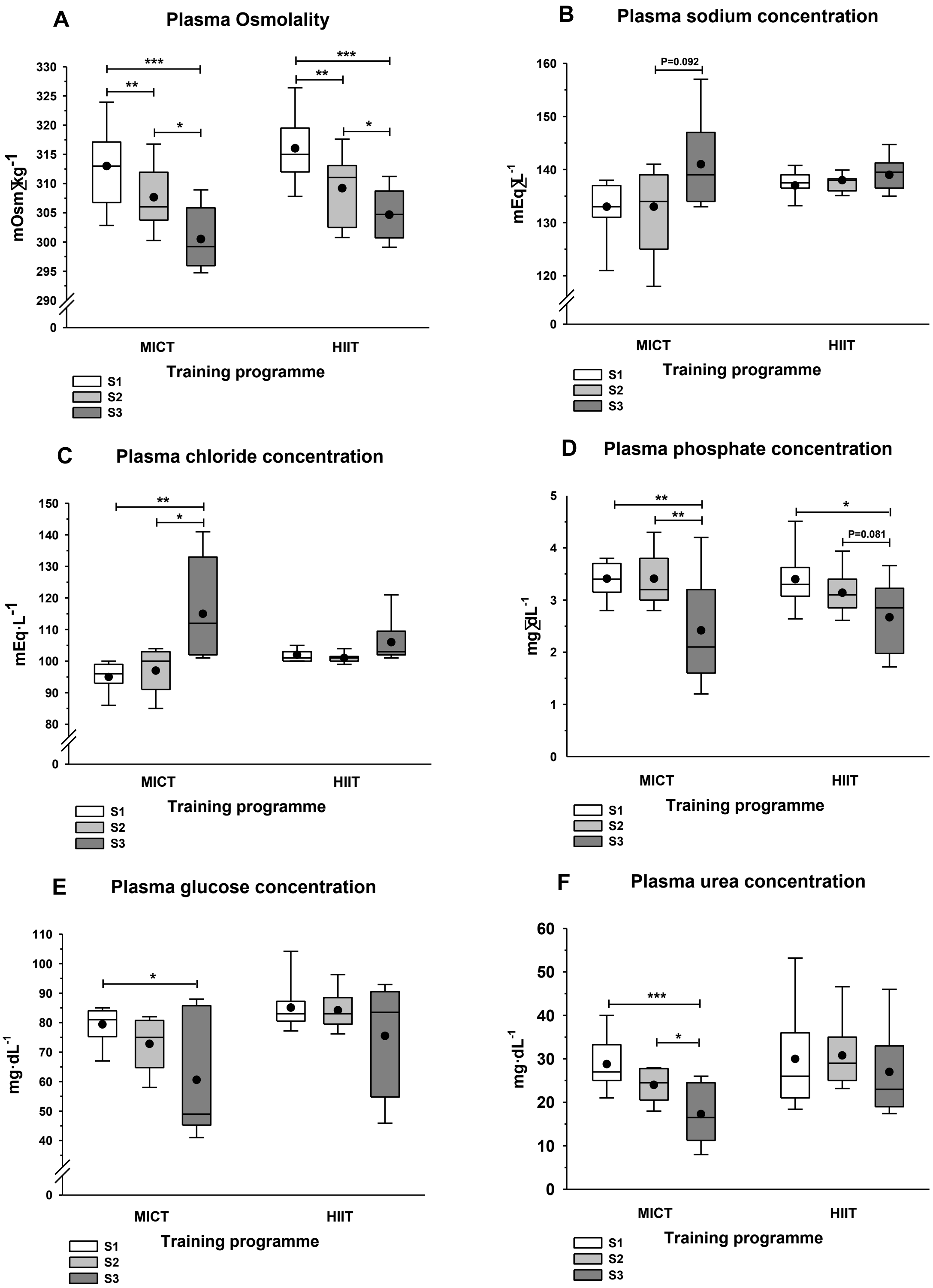
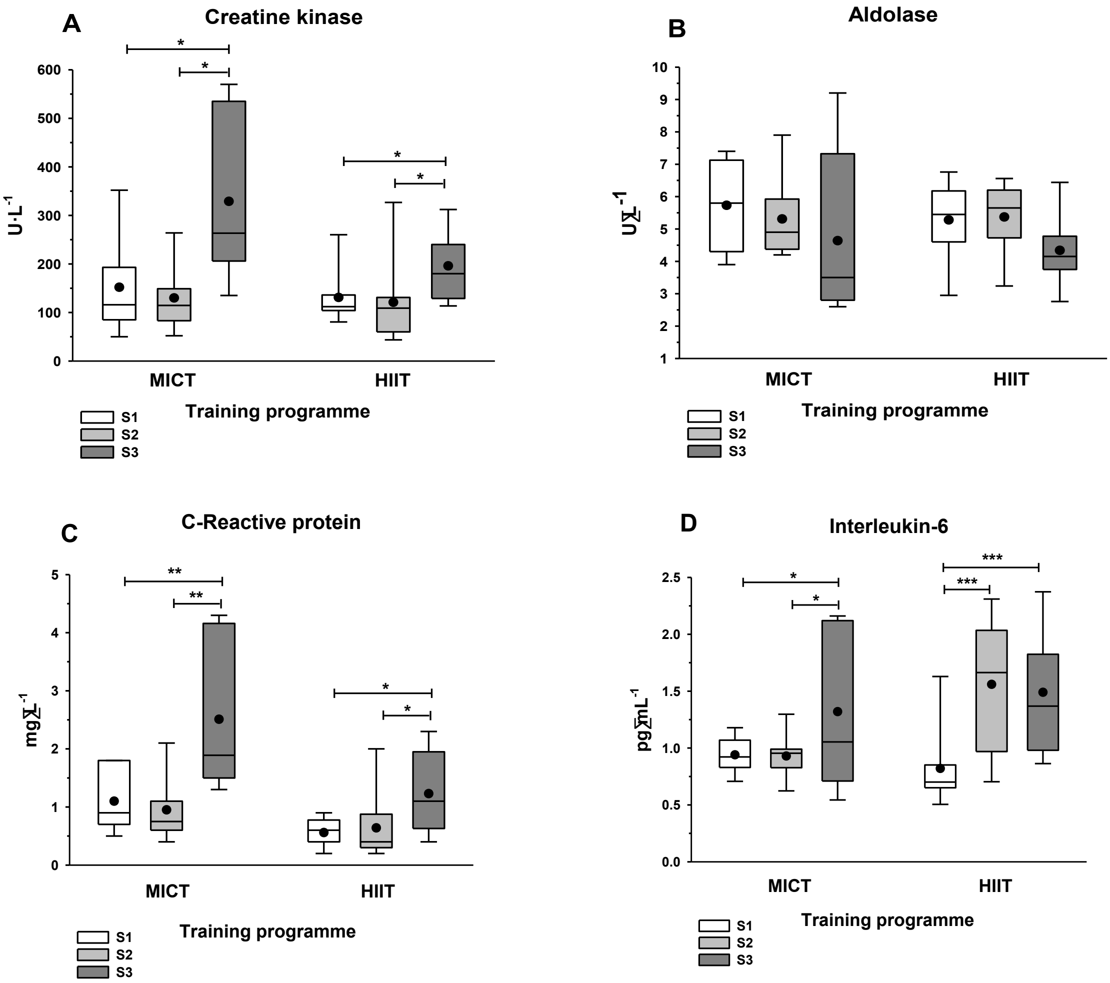

A
Plasma Osmolality
mOsm·kg-1
MICT
HIIT
Training programme
S1
S2
S3
B
Plasma sodium concentration
P=0.092
mEq·L-1
C
Plasma chloride concentration
mEq·L-1
D
Plasma phosphate concentration
P=0.081
mg·dL-1
E
Plasma glucose concentration
mg·dL-1
F
Plasma urea concentration
mg·dL-1

Figure 2.


A
Creatine kinase
U·L-1
MICT
HIIT
Training programme
S1
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B
Aldolase
MICT
HIIT
Training programme
S1
S2
S3
C
C-Reactive protein
MICT
HIIT
Training programme
S1
S2
S3
D
Interleukin-6
MICT
HIIT
Training programme
S1
S2
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Figure 3.

Table 1. Haematimetric indices and formed elements count values (white blood cells and platelets) at three different sampling time points: before (S1) and after MICT or HIIT programmes (S2), and 24 h after the half marathon race (S3). Statistical significant differences shown as asterisk (vs. S1) and hags tag (vs. S2): one symbol ($P<0.05$), two symbols ($P<0.01$), and three symbols ($P<0.001$). Values are means ± SD.

	MICT			HIIT		
Haematimetric indices	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
MCV (fL)	85.6 ± 6.1	86.2 ± 5.9	86.4 ± 5.4	84.8 ± 3.6	85.1 ± 3.3	85.5 ± 3.4*
MCH (pg)	28.4 ± 2.3	27.2 ± 2.5***	27.4 ± 2.2***	28.5 ± 1.6	28.2 ± 1.7	27.2 ± 1.6***###
MCHC ($g \cdot dL^{-1}$)	33.2 ± 0.8	31.5 ± 0.9***	31.7 ± 1.1***	33.8 ± 0.9	33.2 ± 1.3	31.9 ± 0.8***###
Formed elements ($10^3 \cdot \mu L^{-1}$)						
WBC	5.95 ± 1.16	5.83 ± 1.12	6.10 ± 0.96	5.92 ± 1.45	5.43 ± 1.07	6.82 ± 1.54#
PLT	218 ± 45	218 ± 61	190 ± 36*#	209 ± 53	217 ± 42	181 ± 40**##

MCV, mean corpuscular volume; MCHC, mean corpuscular haemoglobin concentration; MHC, mean corpuscular haemoglobin; PLT, platelets; WBC, white blood cells.

Table 2. Liver and lipid panel values at three different sampling time points: before (S1) and after MICT or HIIT programmes (S2), and 24 h after the half marathon race (S3). Statistical significant differences shown as asterisk (vs. S1) and hags tag (vs. S2): one symbol ($P<0.05$), two symbols ($P<0.01$), and three symbols ($P<0.001$). Values are means ± SD.

	MICT			HIIT		
Liver panel	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Total protein ($g \cdot L^{-1}$)	67.2 ± 7.8	63.7 ± 8.5	48.6 ± 17.4***##	72.0 ± 4.2	68.7 ± 4.3	60.2 ± 15.3*
Albumin ($g \cdot L^{-1}$)	40.9 ± 3.5	38.1 ± 4.9	28.8 ± 9.6***##	42.2 ± 3.1	40.0 ± 2.6	35.6 ± 9.5*
Bilirubin ($mg \cdot L^{-1}$)	0.59 ± 0.15	0.47 ± 0.28	0.58 ± 0.41	0.49 ± 0.22	0.45 ± 0.13	0.56 ± 0.27
AST ($U \cdot L^{-1}$)	23.7 ± 5.2	24.4 ± 4.6	24.8 ± 11.0	22.1 ± 3.7	22.4 ± 4.4	23.5 ± 4.6
ALT ($U \cdot L^{-1}$)	12.9 ± 7.7	12.4 ± 3.6	12.7 ± 6.7	11.1 ± 2.5	10.3 ± 4.6	9.8 ± 2.4
GGT ($U \cdot L^{-1}$)	14.9 ± 5.4	17.1 ± 8.2	12.4 ± 7.9	12.9 ± 3.6	13.4 ± 4.5	12.0 ± 3.3
Lipid panel ($mg \cdot L^{-1}$)						
Total cholesterol	193 ± 34	187 ± 32	131 ± 33***##	188 ± 25	187 ± 32	157 ± 33***##
HDL	63.3 ± 8.8	57.9 ± 9.5	51.9 ± 18.9*	61.9 ± 11.6	63.2 ± 9.3	61.9 ± 15.5
LDL	118 ± 29	113 ± 28	72 ± 14***##	113 ± 25	114 ± 27	86 ± 21***###
TAG	62.0 ± 17.2	74.1 ± 16.7	44.3 ± 13.0***##	66.7 ± 20.2	58.5 ± 18.5	54.1 ± 15.4

ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, gamma-glutamyl transferase mean corpuscular volume; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TAG, triacylglycerides.

Table 3. Oxidative stress-related parameters at three different sampling time points: before (S1) and after MICT or HIIT programmes (S2), and 24 h after the half marathon race (S3). Statistical significant differences shown as asterisk (vs. S1) and hags tag (vs. S2): one symbol (P<0.05), two symbols (P<0.01), and three symbols (P<0.001). Values are means ± SD.

	MICT			HIIT		
	S1	S2	S3	S1	S2	S3
TAS ($mmol \cdot L^{-1}$)	1.29 ± 0.11	1.35 ± 0.19	1.27 ± 0.15	1.29 ± 0.14	1.40 ± 0.18*	1.27 ±0.14#
Enzymes ($U \cdot L^{-1}$)						
SOD	15.4 ± 0.7	15.1 ± 0.9	16.4 ± 0.8*#	15.6 ± 1.8	16.2 ± 1.5	16.0 ± 1.5
GPx	986 ± 78	953 ± 73	935 ± 84	846 ± 55	849 ± 76	839 ± 64
GR	58.1 ± 6.8	59.7 ± 5.7	60.0 ± 7.3	59.2 ± 5.2	56.7 ± 4.6	59.6 ± 5.0
Glutathione ($nmol \cdot mL^{-1}$)						
TGSH	4.85 ± 0.85	6.05 ± 1.42	8.85 ± 1.25***##	5.78 ± 0.99	5.06 ± 1.01	8.59 ± 1.25***##
GSH	4.60 ± 0.44	5.53 ± 1.59	8.11 ± 1.44***##	5.42 ± 0.28	5.09 ± 1.06	8.26 ± 1.25***###
GSSG	0.305 ± 1.21	0.200 ± 0.092	0.453 ± 0.12**	0.385 ± 0.152	0.116 ± 0.05**	0.318 ± 0.181#
%GSSG	6.48 ± 2.79	3.10 ± 0.93*	5.19 ± 1.35	6.50 ± 2.84	2.35 ± 1.01*	4.10 ± 1.40

GPX, glutathione peroxidase; GR, glutathione reductase; GSH, reduced glutathione; GSSG, oxidized glutathione; SOD, superoxide dismutase; TAS, total antioxidant status; TGSH, total glutathione.

5
Discusión de los resultados

La motivación principal para plantearse esta tesis era la de explorar qué ventajas podría suponer un entrenamiento HIIT respecto a un entrenamiento MICT a la hora de entrenar y competir en un medio maratón. Nuestro objetivo era valorar si las atletas participantes en el grupo HIIT eran capaces de obtener los mismos o mejores resultados en dicha prueba que las atletas del grupo MICT, que completaban un programa de entrenamiento clásico.

Actualmente, uno de los principales factores para dejar de entrenar es la falta de tiempo (Gibala et al. 2012, Gillen and Gibala 2014, Stutts 2002). Por ese motivo, la clave era diseñar un programa de entrenamiento HIIT que implicara menor tiempo de entrenamiento y, consecuentemente, un menor volumen kilométrico, manteniendo las mejoras en el rendimiento y los beneficios que este tipo de práctica supone para la salud de las atletas.

Los efectos de la aplicación de un protocolo HIIT han demostrado ser beneficiosos en distintos parámetros fisiológicos, además de mejorar el rendimiento. Según la literatura existente, los parámetros fisiológicos que se ven mejorados con entrenamientos intermitentes de alta intensidad son la presión arterial (Way et al. 2019), la capacidad aeróbica (García-Hermoso et al. 2016), la mejora de la condición cardiorrespiratoria (Costigan et al. 2015, Martin-Smith et al. 2020), una mejor sensibilidad a la insulina (Cassidy et al. 2017, Jelleyman et al. 2015) o el aumento del VO_2max (Menz et al. 2019; Milanović et al. 2015). Sin olvidar, que corriendo menos tiempo, también minimizamos el riesgo de lesión, puesto que hay menos volumen semanal total de entrenamiento (García-Pinillos et al. 2017).

Si a los parámetros fisiológicos que mejoran, comentados en el párrafo anterior, añadimos que no hay muchas publicaciones científicas que comparen el entrenamiento HIIT con el MICT, en grupos de mujeres de mediana edad que entrenan a nivel recreativo, y menos todavía, para preparar un medio maratón, pensamos que nuestro estudio puede resultar interesante para profundizar un poco más en este grupo de población. Grupo, que a pesar de estar olvidado en la comunidad científica, es uno de los que ha aumentado más su participación en el *running* en los últimos 10 años, pasando a ser, en algunas competiciones, el 50% de las inscritas (Andersen 2019).

5.1 El Test

El primer paso para el desarrollo de este estudio fue comprobar que el test UMTT podía ser una buena herramienta para nuestro grupo de población, puesto que ya sabíamos que era una prueba sencilla y económica de aplicar, que nos podía facilitar mucho el control del entrenamiento sin tener que pasar constantemente por el laboratorio.

Tal y como discutimos en el artículo I, la intención fue validar la ecuación del test de la UMTT para poder valorar la carga de entrenamiento de ambos grupos, HIIT y MICT, en mujeres de mediana edad. Si bien es cierto que el test UMTT es una de las pruebas más utilizada y recomendada en la literatura científica para estimar en VO_2max, junto con otras mediciones comunes para evaluar el ejercicio de resistencia, como la velocidad aeróbica máxima (MAS) (Billat et al. 1996). Desde que Léger and Boucher lo diseñaron en los años 80, se han hecho comparaciones con otros tests para determinar el VO_2max de manera indirecta, pero ninguno se adaptaba a nuestro grupo de población (Berthoin et al. 1994, Billat and Koralsztein 1996, Dabonneville et al. 2003, García et al. 2014), siendo este el principal motivo del diseño de nuestra ecuación, permitiéndonos así ajustar la intensidad de los entrenamientos de la manera más precisa posible.

Berthoin et al. (1999), en su estudio con adolescentes, observaron que la velocidad medida en la última etapa completada del UMTT permitía una estimación válida de la velocidad asociada con el VO_2max. El UMTT se convierte así en una opción sólida para comparar los datos obtenidos en el campo con los obtenidos en el laboratorio, permitiendo seguir estimando el VO_2max durante el transcurso de las 12 semanas de entrenamiento. Otros autores (Dupont et al. 2010) lo indicaban como un test óptimo para correlacionarlo con ejercicios intermitentes de alta intensidad, con lo que establece una relación favorable para la medición de nuestro grupo HIIT.

5.2 Entrenamiento

El diseño del entrenamiento HIIT está fundamentado en la experiencia profesional como entrenadora y atleta de los últimos 15 años en estas distancias. Apostamos por un tipo de entrenamiento que fuera muy distinto al proporcionado por la literatura científica clásica, que sería el que realizaría el grupo MICT, adaptando el programa de entrenamiento de Galloway and Galloway (2012).

Discutiendo los resultados de ambos grupos, posiblemente deberíamos de haber realizado un rodaje semanal con más volumen kilométrico en el grupo HIIT, pero precisamente este era uno de los puntos con el que queríamos diferenciarlo del grupo MICT, aunque muchas veces se haya considerado un aspecto fundamental para la preparación de las pruebas de fondo, como se comenta en el artículo II.

Gracias a esta diferenciación tan clara entre los dos entrenamientos, donde el grupo HIIT completa las 12 semanas con un 21% menos de distancia (383 km en el MICT *vs* 301 km en el HIIT) y un 17% menos de tiempo empleado (40 h 30 min en el grupo MICT *vs* 33 h 26 min en el HIIT). Conseguimos que con el entrenamiento HIIT hubiera mejora en parámetros como la capacidad aeróbica, la potencia en las series cortas y el rendimiento deportivo junto con otros parámetros ya aportados anteriormente por otros autores como la capacidad oxidativa del músculo y la tolerancia al ejercicio (Gillen and Gibala 2014). Entendemos así que, introducir uno o dos días a la semana de HIIT, podría ser una estrategia a considerar para preparar pruebas atléticas de larga duración en corredoras populares y también para la mejora de la salud.

Es sabido que con el entrenamiento se mejora la condición física, pero *a priori* los entrenamientos HIIT y MICT producen distintas adaptaciones. El ejercicio corto de alta intensidad (HIIT) puede producir adaptaciones en los deportes de resistencia (García-Pinillos et al. 2017) que históricamente se habían reservado únicamente al entrenamiento aeróbico de resistencia (MICT), con estímulos de baja intensidad y larga duración. Entre estas adaptaciones encontramos el aumento de la densidad capilar, las adaptaciones en el músculo esquelético, el aumento del contenido mitocondrial o de la actividad de las enzimas mitocondriales (Gibala 2015, Holloszy and Coyle 1984). A pesar de su condición parcialmente anaeróbica, el entrenamiento HIIT constituye un potente estímulo para inducir adaptaciones fisiológicas, como por ejemplo, aquellas que se dan a nivel mitocondrial, que se asemejan a las anteriormente descritas en el entrenamiento clásico, como es la mejora del potencial mitocondrial del músculo (Burgomaster et al. 2005, Daussin et al. 2008) o los aumentos en el flujo sanguíneo y la conducta vascular del músculo (Krustrup et al. 2004).

El entrenamiento HIIT puede producir mejoras ventilatorias y de la función mitocondrial, mientras que el de larga duración permitiría aumentar el contenido mitocondrial y la capacidad de oxidación de las grasas (Hughes et al. 2018, Lundby and Jacobs 2016). Hay que destacar que algunos autores también observan similitudes en los marcadores mitocondriales y en la capacidad oxidativa del músculo esquelético entre modelos de entrenamiento MICT y HIIT (Hughes et al. 2018), apoyando así la teoría que el tipo de entrenamiento HIIT podría ser una herramienta para mejorar las adaptaciones aeróbicas.

El hecho de que no haya habido un aumento del VO_2max después de las 12 semanas de entrenamiento en ninguno de los dos grupos, especialmente en el HIIT, es un aspecto que podría parecer destacable. En este sentido, pensamos que posiblemente, si hubiera sido un grupo de iniciación o poco experimentado, hubiéramos encontrado resultados en este parámetro. De igual manera, que si el test aplicado en el laboratorio hubiera tenido escalones de 1 min en vez de 2 min, seguramente, habríamos podido apreciar diferencias en el VO_2max, pero quisimos seguir estrictamente el protocolo del UMTT para poder comparar valores de VO_2max y diseñar la ecuación. Esto pudo tener influencia en los resultados del VO_2max, ya que estos escalones de 2 min hicieron que fuera más difícil que las corredoras saltaran un escalón entero del test y poder apreciar mejoras en el VO_2max y en la velocidad final del test.

Sin embargo, siguiendo con el análisis de los parámetros fisiológicos cardiorrespiratorios, sí que encontramos una mayor disminución del VO_2max en los 6 minutos de recuperación post test del grupo HIIT. Esto significa que estas corredoras tienen una recuperación más rápida que las corredoras del grupo MICT. Enlazando con lo descrito en el párrafo anterior, al disminuir el VO_2 peak, implicará una mejor eficiencia ventilatoria, una disminución en el coste energético de la carrera, mejorando así, la economía de carrera de las integrantes del grupo HIIT.

En ese período de recuperación de 6 min, se observa una mayor disminución del V_E y de la FC en el grupo HIIT, indicando una recuperación más rápida, así como una disminución de la FC basal en el mismo grupo, que supondría un aumento de la FC de reserva y por lo tanto, una mejora de la capacidad aeróbica.

La variabilidad individual en la respuesta al entrenamiento la tenemos representada en las figuras 1 y 2 del artículo III, con corredoras respondedoras y no respondedoras. Por un lado, las series cortas en el grupo HIIT, dónde mejoraron el rendimiento anaeróbico sin aumentar la percepción del esfuerzo tal y como indicamos en la figura 3 del artículo II. Y por el otro lado, el grupo MICT, al haber realizado series más largas y con mayor recuperación, no obtiene mejoras en el sistema anaeróbico, pero en cambio, sí tienen la percepción de un mayor esfuerzo, contrariamente a lo que sucede con los entrenamientos de rodajes largos, donde este grupo, el MICT, al haber hecho tantos kilómetros, disminuye esta percepción del esfuerzo cuando realiza este tipo de entrenamiento. Así pues, esta variabilidad de la respuesta, que otros autores ya indicaban que podría estar relacionada con el parámetro evaluado, y que para cada uno de ellos, se podía obtener una respuesta positiva, negativa o sin modificación (Mann et al. 2014) en nuestro caso en particular, podemos afirmar que el grupo MICT tiene más respondedoras en los rodajes largos y en porcentaje de cambio en el VO_2max obtenido en el laboratorio; mientras que el grupo HIIT tiene más respondedoras en la potencia obtenida en el entrenamiento de series y en la mejora del resultado final del medio maratón.

Otro factor importante a tener en cuenta es que las corredoras del grupo HIIT comentaron que el entrenamiento interválico les resultaba más entretenido que el entrenamiento continuo. Esto no sucedió con el grupo MICT, que expresaron que se les hacían muy duros los rodajes largos, como ya ha sido apuntado por otros autores (Bartlett et al. 2011)

En referencia al trabajo de fuerza con el propio peso corporal y ejercicios pliométricos que realizamos con el grupo HIIT, posiblemente tendríamos que haber realizado un protocolo de test de saltos para ver si había mejoras, puesto que algunos autores encontraron un correlación entre la mejora de las marcas en carreras de 5 km sin mejorar el VO_2max después de un trabajo de fuerza explosiva a través de ejercicios pliométricos que aumentan la adaptación neuromuscular (Paavolainen 1999), sin mejorar el VO_2max (Sunde et al. 2010).

Se ha demostrado que la aplicación de un programa de entrenamiento HIIT en personas jóvenes sanas con una condición física dentro de la media, han obtenido adaptaciones musculo esqueléticas, mejora de la capacidad oxidativa y aumento del rendimiento, similares a un programa de entrenamiento tradicional de resistencia (Gibala 2015). Después de analizar en profundidad nuestros resultados expuestos en los 4 artículos presentados en este documento, podemos añadir que estos beneficios también se encuentran en el grupo de población estudiado, es decir, mujeres de mediana edad con una condición física que les permite correr un medio maratón. No es que se puedan substituir todos los beneficios del ejercicio de resistencia clásico, puesto que las adaptaciones de este tipo de ejercicio podrían ser a más largo plazo, contrariamente a los aplicados en el HIIT, donde las adaptaciones serían más rápidas.

La mejora del grupo HIIT en la recuperación del VO_2, la potencia en el entrenamiento por intervalos, el tiempo final en el medio maratón, como se indica en los artículos II y III, sugiere que podría ser un entrenamiento más eficiente y efectivo en términos de volumen/tiempo semanal total que el que siguió el grupo MICT. Aunque posiblemente la combinación de un entrenamiento semanal con más volumen que el aplicado en el grupo HIIT, un programa mixto, podría haber dado mejores resultados en este grupo sin llegar a ser el volumen aplicado en el grupo MICT, pero esto quedará para futuras investigaciones.

En el apartado hematológico, las extracciones de sangre realizadas en los períodos S1, S2, como podemos observar en las figuras 1, 2 del artículo IV, no se observaron diferencias significativas en los parámetros de RBC, WBC, Hb, plaquetas, ni perfil lipídico ni hepático (Tabla 2, artículo IV) después de las 12 semanas de entrenamiento. En cambio, el hematocrito aumentó en el grupo MICT. También hubo una disminución de la osmolalidad relacionada con el aumento del volumen sanguíneo.

Tampoco se encontraron diferencias significativas después del periodo de entrenamiento en los marcadores de daño muscular e inflamación como observamos en la figura 3 del artículo IV. Sin embargo, sí que hay diferencias significativas en los marcadores de estrés oxidativo (Tabla 3, artículo IV), dónde el efecto de las 12 semanas de entrenamiento produjo un aumento del TAS y una disminución del porcentaje de GSSG, es decir, que ambos entrenamientos aumentaron la capacidad antioxidante total, aunque en el grupo HIIT fue más evidente.

5. 3 Medio maratón

Varios autores describen mejoras de rendimiento entre el 3% y el 7% en tiempos de carrera después de aplicar distintos protocolos de HIIT (Bangsbo et al. 2009, Esfarjani and Laursen 2007), muy parecidas a las que hemos obtenido en ambos grupos de entrenamiento. Las mejoras en el grupo HIIT y MICT fueron del 2% y 3% respectivamente, como indicamos en el artículo II. Podría parecer una mejora poco relevante al no ser significativa, pero es muy importante tener en cuenta que se trata de mujeres que previamente al estudio entrenaban un mínimo de 3 días a la semana y con experiencia en medio maratón. Por lo tanto, es más difícil obtener mejoras de rendimiento cuando trabajas con grupos ya experimentados y un buen historial de entrenamiento.

A pesar de no ser atletas profesionales, estas corredoras amateurs entrenaban, previamente al estudio, 3 días a la semana de media, completando unas 5 h semanales de *running*. Venían de hacer un período de descanso vacacional en el mes de agosto. Con estas circunstancias, mejorar las marcas en medio maratón no sería una tarea fácil, puesto que al tener experiencia en entrenamiento y también en la prueba del medio maratón, dificultaba que se produjeran grandes mejoras de rendimiento.

Observando el resultado final de las marcas en el medio maratón, presentadas en el figura 2 del artículo II, se ve que no son mejoras significativas, pero si analizamos los resultados con detenimiento podemos sacar conclusiones interesantes. El grupo MICT mejoró 3 min 50 s en relación con las marcas previamente realizadas, mientras que el grupo HIIT mejoró 2 min 29 s. No se trata de resultados estadísticamente significativos, pero si hablamos con cualquier persona que practique *running*, y le decimos que va a reducir su marca en medio maratón en más de 2 minutos, con toda probabilidad decidirá seguir el plan de entrenamiento. Y si comparamos estos resultados con una carrera de medio maratón, por ejemplo el medio maratón de Barcelona, vemos que se mejorarían entre 73 y 90 posiciones dentro del grupo de edad de 40-49 años. Por lo tanto, aunque la mejora a nivel estadístico no sea significativa, desde el punto de vista de rendimiento, es una mejora muy importante.

Nos encontramos con que no todas las corredoras responden de la misma manera y este es uno de los motivos por los cuales hay una dispersión en el resultado y que posiblemente motiva esa falta de significación estadística en las marcas finales del medio maratón. Por esta razón, ya en el artículo III, apuntamos que es fundamental individualizar la prescripción del ejercicio para ajustar a cada corredora cuál es el método de entrenamiento que mejor le podría funcionar.

En los parámetros hematológicos post medio maratón que podemos observar en la figura 1 del artículo IV, no se observaron diferencias significativas en los parámetros de RBC y Hb. Sin embargo, sí se aprecian diferencias significativas en el grupo MICT, con un descenso del hematocrito que podría estar relacionado con la hemólisis producida por la pisada, el estrés oxidativo o el desajuste osmótico en los RBC, tal y como algunos autores han indicado en estudios similares (Duca et al. 2006). Se podría apuntar que el grupo HIIT, al haber realizado un entrenamiento con más impacto, podría haber desarrollado mecanismos de protección frente a estos desajustes.

También encontramos un aumento significativo de los WBC (Tabla 1 artículo IV) en el grupo HIIT, como respuesta al proceso inflamatorio provocado por el ejercicio, especialmente, el ejercicio de alta intensidad, que ya se ha descrito anteriormente (Pizza et al. 1995, Duca et al. 2006). Las PLT descienden de manera significativa en ambos grupos, efectos descritos como protrombosis a las 3 h post medio maratón por un mayor adhesión plaquetaria y reparación del daño en el endotelio capilar (Lippi et al. 2018), también descrito a las 24 h después de un maratón (Traiperm et al. 2013).

Por otro lado, hay una disminución de la concentración plasmática de glucosa, fosfatos, urea, proteínas totales y albúmina en ambos grupos, mientras que la osmolalidad se reduce en mayor medida en el grupo MICT. Está descrito que en procesos inflamatorios agudos se produce una hipoalbuminemia (Soeters et al. 2019), que al ser más acusada en el grupo MICT, indicaría que hay una mayor inflamación sugiriendo, por tanto, que el grupo MICT toleró peor el esfuerzo agudo que supone el medio maratón comparado con las corredoras del grupo HIIT.

En cuanto al perfil lipídico, llama la atención que el grupo MICT disminuyo todos los indicadores, con un descenso del 30% del colesterol total vs un 16% del grupo HIIT, un 10% del HDL vs sin diferencias en HIIT, un 36% del LDL vs un 25% en HIIT y finalmente un 40% del TAG que no varía en el grupo HIIT (Tabla 2 del artículo IV). Esta variación en los parámetros, podría indica que la intensidad del entrenamiento determinaba la vía metabólica y el substrato utilizado como fuente de energía durante el medio maratón, afectando a este perfil lipídico 24 h después de la carrera. Así, el grupo MICT consume más lípidos, pero tendríamos que hacer estudios adicionales para poder determinar si el grupo HIIT consume realmente menos lípidos y si es debido a una mayor eficiencia energética o por usar otras vías energéticas.

Si nos centramos en los marcadores de daño muscular e inflamación (figura 3, artículo IV) encontramos incrementos significativos en los marcadores CK y CPR, que indican el efecto agudo del ejercicio máximo. Después de realizar el medio maratón, el grupo MICT tiene aproximadamente 3 veces más respuesta lesiva e inflamatoria que el grupo HIIT y además, una mayor dispersión en los resultados, es decir, que hay una mayor variabilidad inter-individual dentro del mismo grupo. Sin embargo, el grupo HIIT tiene una respuesta de daño muscular e inflamatoria mucho menor y con menos variabilidad inter-individual, que estaría relacionado con el hecho que este grupo realizó rutinas de fuerza y ejercicios excéntricos que podrían haber preparado mejor la musculatura dotándola de una mayor protección ante el impacto agudo del ejercicio.

Finalmente, el medio maratón produjo una situación de estrés oxidativo, demostrado por el aumento de los valores GSSG, además del aumento de los valores de GSH en plasma y de SOD, este último sólo en el grupo MICT, que podría justificarse como una condición de menor protección ante el estrés oxidativo y derivado de un mayor daño muscular.

5.4 Limitaciones

- Existen un número escaso de publicaciones científicas que estudien el grupo de población analizado en esta tesis, mujeres de edad premenopáusica con experiencia en competiciones de larga distancia, lo que hace difícil una discusión más rica científicamente.

- Limitación en cuanto al número de sujetos que participaron en el estudio. Es difícil realizar estudios longitudinales controlando todo el periodo de entrenamiento, puesto que 12 semanas de periodización implica que los sujetos estén disponibles todos esos entrenamientos, teniendo que ceñirse a un control continuado que no siempre es fácil. Una posible solución sería plantear un estudio de menor duración y con una mayor y más diversa población de estudio.

5.5 Perspectivas de futuro

Sería de gran ayuda para los entrenadores poder realizar un estudio con un volumen mayor de sujetos y menor en semanas de entrenamiento para intentar diseñar un algoritmo que permita discernir a los sujetos respondedores y no respondedores. Esto implicaría poder ajustar al máximo el tipo de entrenamiento más conveniente para cada sujeto, no sólo por el volumen de kilómetros o la intensidad, sino cómo deben de ser esos kilómetros, la recuperación entre series realizadas y/o entre días de entrenamiento i otros factores que afectan al seguimiento y resultados de un plan de entrenamiento.

6

Conclusiones

6.1 Conclusiones generales

Las investigaciones desarrolladas a lo largo de esta memoria de tesis han demostrado que el seguimiento de dos programas de entrenamiento de 12 semanas de duración (HIIT o MICT), en mujeres de mediana edad y nivel *amateur*, han promovido una respuesta similar en el rendimiento en un medio maratón sin ofrecer una repercusión negativa en diferentes parámetros fundamentales para la salud.

6.2 Conclusiones específicas

- La creación y utilización de la ecuación para el cálculo indirecto del consumo máximo de oxígeno a partir de un test de campo, nos ha permitido adaptar las cargas de entrenamiento durante las 12 semanas del estudio. Esta herramienta podrá ser utilizada por entrenadores y/o corredoras *amateurs* en sus entrenamientos permitiendo estimar el VO_2max en el campo y también podría evaluar, sobre el terreno, la aptitud física de las mujeres de mediana edad, uniendo esfuerzos encaminados a preservar su salud, optimizar y mantener la práctica del ejercicio físico.
- El plan de entrenamiento HIIT mejoró tanto el rendimiento anaeróbico como el aeróbico, con una recuperación más rápida en las pruebas máximas, implicando un 21% menos de volumen de entrenamiento y un 17% menos de tiempo de entrenamiento en comparación con las mujeres que realizaban el entrenamiento MICT.
- Ambos grupos redujeron sus marcas medias previas: 3 min 50 s (MICT) y 2 min 29 s (HIIT). Pese a las reducciones en tiempo y volumen, el grupo HIIT obtuvo una marca media 4 min 21 s menor a la obtenida por el grupo MICT. Por tanto, un protocolo de entrenamiento donde predomina la intensidad en detrimento del volumen, puede proporcionar

un modelo de ejercicio alternativo para la mejora de los resultados de media maratón en corredoras *amateur*.

- El grupo HITT mejoró el rendimiento anaeróbico sin aumentar la percepción del esfuerzo, mientras que no hay mejora anaeróbica en MICT aunque sí que presenta una mayor percepción del esfuerzo durante las series de potencia. Por el contrario, el entrenamiento MICT disminuye la percepción del esfuerzo en el rodaje largo.
- En las pruebas de laboratorio, el grupo HIIT presentó menores VO_2, V_E y FC en las fases de reposo post-ejercicio (minutos 3 a 6) indicando una recuperación más rápida que MICT.
- A iguales cargas de carrera, el grupo HIIT presentó menores VO_2 pico indicando una mejor eficiencia ventilatoria que podría derivar de un menor coste energético y/o mejoras en la economía de carrera a altas velocidades.
- Se observó una disminución significativa de la FC basal en HIIT (no en MICT) sugiriendo una mejora de la FC de reserva.
- Debido a las diferentes respuestas individuales observadas en distintos parámetros fisiológicos y de rendimiento, deberemos ajustar de forma individual las cargas de entrenamiento para obtener la mejor respuesta de cada una de las correderas, consiguiendo respuestas positivas en una mayor proporción de las practicantes.
- No se observan diferencias importantes en los resultados obtenidos, tanto en los parámetros bioquímicos como en los hematológicos, después del período de entrenamiento entre los dos grupos estudiados.
- Contrariamente, la respuesta aguda producida por el ejercicio máximo que supone correr una media maratón (valorada a las 24 h de su finalización) indujo una serie de alteraciones hematológicas y plasmáticas compatibles con un estado temporal de fatiga y estrés.

- Algunas de las alteraciones observadas a las 24 h de la competición, fueron diferentes en función del protocolo de entrenamiento seguido dependiendo de la intensidad, el volumen de carrera y la duración.
- El programa de entrenamiento seguido influyó en el perfil lipídico observado a las 24 h después del medio maratón.
- El grupo MICT toleró peor que HIIT el esfuerzo agudo que supone la media maratón presentando valores superiores en los marcadores de daño muscular, procesos inflamatorios agudos y estrés oxidativo.
- La posible naturaleza del entrenamiento HIIT, con intervalos de alta intensidad y trabajo de fuerza, podría proporcionar una mejor adaptación a la hora de la competición. La exposición de manera reiterada a mayores ratios de consumo de oxígeno e, incluso, al uso del metabolismo anaeróbico, consecuencia de un trabajo a mayores intensidades durante el entrenamiento, podría haber estimulado respuestas fisiológicas adaptativas más intensas.

7

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